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THE DEVELOPMENT OF MOTOR CO-ORDINATION IN YOUNG CHILDREN

An Experimental Study in the Control of Hand and Arm Movements

by

BETH WELLMAN, PH.D.

PUBLISHED BY THE UNIVERSITY, IOWA CITY

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PROFESSOR BIRD T. BALDWIN, PH.D., Editor

FROM THE IOWA CHILD WELFARE RESEARCH STATION

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FOREWORD

A detailed analysis of the psychological and physiological factors in motor control of the hand and arm furnishes the problem for this investigation in the motor coördination of young children. Dr. Wellman has adapted the tracing board for laboratory use with young children and has devised a practical tracing path for laboratory use with children and adults. Her data include approximately 8,000 individual records on eight selected directions of movement, by 136 little children.

The method is experimental and analytical, with significant results with regard to individual differences, handedness, age, and the influence of direction of movement, suggestion, and practice. No apparent sex differences are found, apparently no transfer from one direction to another, and no close relationship between intelligence and these special motor abilities. The bibliography furnishes valuable references in the field of motor control, and the conclusions from the study have a direct bearing on motor development and training of little children in motor coördination.

This study was accepted as a partial fulfillment of the requirements for the degree of doctor of philosophy in child psychology. Other investigations of the grosser movements of the legs, arms, hands, and fingers in manual play and physical activities are also being pursued in our Preschool Psychological Laboratories with a view to making a comprehensive study of motor development during the first six years of childhood.

BIRD T. BALDWIN

Office of the Director
Iowa Child Welfare Research Station
State University of Iowa
May 1, 1926

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CHAPTER I

STATEMENT OF THE PROBLEM

In almost every aspect of the young child's life, demands are being made upon his ability to coördinate his movements. In building blocks, in stringing beads, in buttoning his coat, in lacing his shoes, in eating, in scribbling or writing, fine coördinations of the hand and arm are required. Observation of young children convinces one that there are differences in the ability of different children to make these adjustments. Just what the differences are, how to measure them, and how they are related to other phases of the child's development are questions around which little experimental work has been centered.

The present investigation represents an approach to the study of some phases of the development of motor coördination in young children. The main specific objectives were (1) to make an analysis of the influence of direction of movement on control of the hand and arm in young children; (2) to analyze the muscular and psychological factors involved in such control; (3) to note age, sex, and individual differences; and (4) to determine the relative development and control of right and left hands. It was hoped ultimately to contribute to the problem of what constitutes motor control, of whether it is possible to establish a motor index, and of what place motor ability takes in the child's developing abilities.

Two experiments were planned with these objectives in mind. The apparatus for the first experiment is an adaptation of the Stoelting tracing board for use with very young children. The materials for the second experiment consist of sheets of paper on which are printed two lines with a space between of the same dimensions as the tracing board path; between these lines the child attempts to draw a line with a pencil. The experiments are described in detail later in the study.

Motor coördination of the hand and arm was studied in each experiment by means of movement in eight directions:

Direction 1 (↓), down
Direction 2 (→), left to right
Direction 3 (↑), up
Direction 4 (←), right to left
Direction 5 (↙), right to left down
Direction 6 (↘), left to right down
Direction 7 (↗), left to right up
Direction 8 (↖), right to left up

For the last four movements the tracing board and the paper with the printed path were placed at an angle of 45 degrees to the base line of the table.

The laboratory conditions were especially favorable for carrying on intensive investigations with young children. Children from two to five years of age were in regular daily attendance at the Preschool Laboratory and Junior Primary Group of the Iowa Child Welfare Research Station, and the six-year-old children were in attendance in the first grade of the University of Iowa Elementary School. All were present for from one and one-half to three hours each morning and could be taken to special examining rooms for individual work at any time during the morning. All of the children were acquainted with the examiner and with the conditions of the laboratories before the experiments were begun.

For the main experiments, 136 children served as subjects; many of the children were subjects for repeated tests or special experiments. Their attitude toward the experiments expressed good coöperation, curiosity in regard to the working of the tracing board, and interest in good performance.

CHAPTER II

PUBLISHED EXPERIMENTS IN MOTOR CO-ORDINATION

Motor coördination may be studied from a number of angles, depending upon whether the movements are voluntary or involuntary and upon the particular characteristic or characteristics of movement involved. When voluntary movements have been studied, the rate, accuracy, precision, force, and extent of movement have been the subjects of investigation. When involuntary movements have been studied, the chief concern has been the extent of movement.

Since the force of movement involves structural growth to a greater degree and actual control to a less degree than the other characteristics do, it is not considered in the following discussion of the published findings relating to motor coördination.

EXPERIMENTS WITH YOUNG CHILDREN

Experiments with Children Less Than Five Years of Age

Since 1923 a few significant and extensive experiments have been published on the growth of motor coördination in children below school age. Prior to that date, preschool children were studied only as they were more or less incidentally included in groups with older children, when the concern was largely in differentiating older and younger children rather than in differentiating the younger children themselves.[1]

Gates and Taylor,[36] in 1923, studied the acquisition of motor control in writing by forty-five preschool children. Two groups were taught to write, one by tracing letters and the other by copying them. A series of five letters was first practiced for several days, then another series of five letters. The scores made by the group who traced were higher than those made by the group who

1. Of the earlier experiments mention should be made of the reports of Kelly,[57] who tested tapping rate and the extent of the least possible movement of the shoulder and finger in children as young as four years; of Wyczolkowska,[112] who classified the spontaneous scribblings of some children (the number is not stated) from two to six years of age; and of the maze tests by Cunningham,[23] Shaw,[93] Porteus,[80] and Young.[115]

wrote, but their ability to write letters at the end of the experiment was considerably less, that is, there was little transfer from the tracing situation to an actual writing situation.

The first comprehensive investigation on motor coördination in preschool children was that of Baldwin and Stecher,[5] who gave a large number of tests to 105 children from two to six years of age. They included several tests that involve motor control in combination with form perception, as well as six tests of more strictly motor coördination. These six tests were the tracing path, Porteus maze, three hole, perforation (in which the child punches holes in a paper), walking board, and a test with seven Montessori dressing frames. Correlations of the tests with each other and of the motor tests with tests of mental ability were given, together with partial correlations when mental age was constant and when chronological age was constant. The correlations among the motor tests that remained highest after the effects of mental age and chronological age had been eliminated were the tracing path with maze and three hole, maze with three hole, and three hole with perforation. The raw correlations of the motor tests with Stanford-Binet and Detroit kindergarten tests were high, and were still positive when chronological age was held constant, the partial coefficients being largest for the three hole and Porteus maze. Sex differences were slight.

This report was followed closely by the works of Gesell[39] and of Johnson.[53] Gesell tested 500 children from birth to six years of age, including for the very young infant such abilities as holding up the head, creeping, walking, and picking up an object. The tests at the older levels included writing movements, maze tests, a steadiness test, in which the child catches a cardboard fish by putting a stick through its eye, and drawing a picture. Gesell combined his tests into tentative norms for diagnostic purposes, but gave no discussion of the interrelations of the various tests, and his system of scoring makes comparisons with the results of others rather difficult.

Johnson[53] used four motor tests with 260 children from three and one-half to thirteen and one-half years of age. These tests were tapping, steadiness, throwing a dart at a target, and maze tracing. Johnson found an increase in score with chronological age for each of the tests, the increase being least marked for steadiness. The

maze coördination test was found to be a good measure at four, five, and six years of age. In tapping, girls excelled boys at every age except four years. No consistent sex differences were found for steadiness. Correlations between tapping and steadiness and the weight-height index were insignificant.

Experiments with Children of Five and Six Years of Age

Tests have been used more extensively with children of five and six years than with younger children, undoubtedly because of the greater accessibility of children in the schools. Tapping, steadiness of the hands, arms or body, plunger, aiming, or target tests, maze tests, tracing board, walking board, writing movements, crossing out dots, string games, balancing coins, threading needles, tying string, interlacing slats, moving one hand in a circle while patting the head with the other, and thumb and finger opposition are tests that have been reported by various investigators for these ages.[2]

In general, the results of these investigations showed a marked increase of motor control with age, a positive relationship with general mental ability, and an indication of superior performance by children from superior environment. Findings in regard to sex differences were contradictory.

EXPERIMENTS WITH THE TRACING BOARD

The tracing board was first invented and used by Bryan,[13] in 1892. His tracing board differed from the commercial instrument now used in that it utilized tin foil and that the two strips came together at one end of the path. Little use has been made of the tracing board with children since the time of Bryan, and his complicated system of scoring has been discarded.[3]

The tracing board has been found to give a good index of handedness in children. Better results have been obtained with the positive instruction "Go down the middle of the groove" than with the negative instruction "Do not touch the sides." For both children and adults the scores have been higher for movements that are

2. The investigators who have used one or more of these tests are: Beeley,[7] Berry and Porteus,[8] Bickersteth,[9] Bolton,[12] Bryan,[13] Burt,[16] Carlisle,[19] Conway,[20], Foote,[27] Freeland,[28] Freeman,[30] Gesell,[39] Gilbert,[40,41] Hancock,[47] Hunt, Johnson, and Lincoln,[50] Johnson,[51,53] Kirkpatrick,[58] Lamprey,[61] Mead,[66] New York State Board of Charities,[70] Ream,[87] Rogers,[90] Smedley,[95] Starch,[97] Tow,[102] and Town.[103]

3. The test has been included in a series of tests with children by Bolton,[12] Beeley,[7] and Town.[103] With adults it has been used by Thompson,[99] Langfeld,[62] Gates,[35] Link,[63] Perrin,[75] and Rudisill.[91]

toward the body than for movements that are away from it. No correlation has been found with other motor tests nor with tests of intelligence for adults. Sex findings have been contradictory.

EXPERIMENTAL ANALYSES OF WRITING MOVEMENTS

Analysis of the conditions affecting the muscular coördinations required for handwriting and similar movements has been a subject of some interest to experimenters. Reference has already been made to the work with preschool children by Gates and by Gesell.

Scripture and Lyman,[92] in 1892, tested the ability of ten boys about thirteen years of age to draw lines in four different directions. Smaller amounts of deviation from a true straight line were found for the two vertical and horizontal lines than for the two angle movements. The most nearly accurate line was down and the least nearly accurate line was the angle movement from the left down.

Speed and pressure changes in writing were investigated with children and adults by Freeman,[29,31,32] and with adults by Binet and Courtier.[10] Differences in speed changes and in pressure were found between good and poor writers and between children and adults. There was retardation in speed at turns, or changes in direction, the retardation being less for children than for adults. Good writers used a looser grasp of the pen than poor writers.

Rhythm in handwriting was studied by Nutt[74] and by West,[106] who found that children were low in rhythm.

Speed in making vertical marks was reported by Kirkpatrick[58] and the slope of letters by MacMillan.[65]

Although the Porteus maze tests were intended by their author to measure mental alertness, prudence, forethought, and the power of sustained attention, they have been used by other investigators for determining motor control in young children, since success for the young child depends largely upon his ability to make the required coördinations. The movements involved are closely related to writing movements.[4]

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4. The investigators who have used maze tests with young children are Norsworthy,[72,73] Mead,[66] Cunningham,[23] Shaw,[93] Porteus,[78,80,82] Berry and Porteus,[8] Burt,[16] Town,[103] Morgenthau,[68] Baldwin and Stecher,[5] and Gesell.[39] A variation worked out in the Johns Hopkins University laboratories has been used with young children by Johnson.[53] The maze as a motor learning problem with young children has been reported by Young.[115]

CHAPTER III

PROCEDURE OF EXPERIMENTS

Two experiments were planned for the study of the young child's ability to coördinate his movements in eight fundamental directions. In the preliminary experiment the apparatus used was a modification of the Stoelting tracing board. Fifty-four children from three to six years of age acted as subjects. As an outgrowth of this preliminary experiment, a tracing path test was originated, which served as the basis for the main experiment and for the special experiments on the factors contributing to control of movement. In the experiments with the tracing path 136 children from three to six years of age were subjects. This number included the fifty-four children of the tracing board experiment. Many of the children served as subjects for repeated tests and in a series of special experiments.

TRACING BOARD EXPERIMENT

Materials

The Stoelting tracing board, commonly used, consists of a wooden block upon which is set a glass path 25 cm. long, 5 mm. wide at the top, and 1 mm. wide at the bottom, with brass strips and a raised rule on either side of the glass. The subject attempts to proceed down the glass path with a metal stylus without coming into contact with the brass strips. As soon as contact is made, there is a sound of an electric buzzer or bell, which is wired in circuit with the tracing board. The distance the subject has traversed when he makes the first contact is noted from the rule and is usually recorded as the score.

It was believed that the noise of the buzzer might prove so attractive to little children when they are subjects that their delight in hearing the buzzer might invalidate the results. To safeguard against this, a tracing board was designed for this experiment in which the metal and glass parts are reversed from the Stoelting model so that the buzzer sounds continuously while the stylus is on the path. A paper rule was placed under the glass and all parts were sunk into the wooden background, so that a smooth surface

is presented, over which the stylus glides easily from brass to glass instead of being blocked by the rule, as in the Stoelting model. A short binding post that would interfere as little as possible with a free range of movement over the whole board was used. A special stylus with a point considerably shorter than the regulation point of the Stoelting stylus was made of aluminum in order to avoid scratching the brass and glass (Figure 1).

Method of Conducting Experiment

The child stood before a low table on which the apparatus rested. The height of the table was adjusted to the child's height so that he naturally took a position with the elbow flexed at right angles and the forearm resting on the table. Eight positions of the tracing board for the different directions of movement were used. Four directions, three trials in each direction, constituted one day's performance for a child. The sequence of directions was as follows:

First day, directions 1 (↓), 2 (→),
3 (↑), 4 (←), right hand
Second day, directions 1, 2, 3, and 4, left hand
Third day, directions 5 (↙), 6 (↘),
7 (↗), 8 (↖), right hand
Fourth day, directions 5, 6, 7, and 8, left hand

This sequence was kept the same for all children. For a study of the influence of the difficulty of particular directions on scores, it is desirable to use different sequences of directions with equated groups. However, development is so rapid at the ages concerned in this investigation that if further subdivision were attempted, the groups at any one stage of development would necessarily be too small for reliable conclusions. The possibility of changes in difficulties of directions with increasing age made it inadvisable to equate the groups irrespective of the range of ages. In view of these considerations and the fact that considerable labor was involved in the mere mechanics of keeping groups equated for individual tests extending over a period of three years, it seemed best to maintain the same sequence of directions for all the children used in this investigation, and to interpret the data accordingly.

The sequence of specific directions was decided upon from an *a priori* standpoint of possible difficulties, practice effects, and transfer of training.

Care was taken to include only positive suggestion in the in-

structions and in the supplementary remarks that were sometimes necessary, such as to finish the trial, to go slowly, or to assume a correct position, since Langfeld[62] found with his adult subjects with the tracing board test that much better results were obtained when the subject was instructed, "Go down the middle of the groove" than when he was told, "Do not touch the sides."

The instructions were: "See this pencil. I'm going to go right down this path [pointing] with the pencil. As long as I keep on the path the buzzer over here [indicating] will make a noise. Now watch me. [The experimenter demonstrated by going the entire length in fifteen seconds, saying at the same time, "I'm going to try to keep going down the path all the time."] Now you do it."

The child was then given the stylus in his right hand and shown how to hold it in the ordinary writing position, with the body erect and both feet firmly on the floor. For directions 2, 3, and 4, the instructions were, "Now we want to begin here and go this way." When the child came the second day, the instructions were shortened to, "You remember this game, don't you? Try to keep in the path all the time." Generally after the first day's performance no further instructions were needed as to the direction the movement was to take. When the child seemed uncertain, or hesitated, the experimenter said, "Begin here and go down (or up) this way."

The child was not instructed to stop at the first contact, as is the usual method with the tracing board test, but finished the entire length of the path each time. This change was made in order to get a record of the entire movement, to avoid interruptions, which are irritating to the child, and to prevent confusion in the child's mind as to what was desired.

Method of Scoring

All points of contact during the entire course of the movement and the amounts off path at each contact were recorded in half centimeters and the time for each trial was taken with a stop watch. Two methods of scoring the results were thus possible: The first score was the point of first contact or distance that the child had gone when he first went from the brass to the glass, and the second score was the percentage of the total path, 25 cm., that the stylus was on the path. In calculating the percentage on the path each contact was counted as 0.5 cm. off path. The average of three trials was used in each method.

Response of Children

Good interest and careful effort were maintained throughout the course of the experiment, with, of course, certain daily fluctuations. The children did not seem to lose their interest in the test with the repeated performance; in fact, they often clamored for a chance to "play" with the examiner when it was not their turn, and were much pleased at playing a familiar game. It was extremely difficult to know at times whether the child's interest and attention were lagging in a poor trial, or whether the difficulty lay in his inability to control the movement. Frequently these two factors seemed to go together, that is, if the child could do well, his interest was maintained, while if he was deficient in control, he lost interest.

It is, of course, difficult to secure from preschool children any systematic introspective observations on a test. If a leading question was asked, the child became reticent and no help was forthcoming. When he felt that the experimenter was in sympathy with him, he might volunteer significant remarks on the test, which helped to give an insight into his problems and his understanding of the task. Some children, for example, indicated that they perceived a difference between the wider and narrower ends of the path by such remarks as, "It's upside down," when the apparatus was turned for the movement away from the body, "Kind of hard to get from down here up to here, that little part," or "That end's so little, I can't hardly do it that good," and by beginning at the wider end without indication from the experimenter as to where to begin. At times the experimenter waited to see where the child would begin if not directed; the child usually began properly, but was unable to give a reason for so doing.

With some children the remark that as long as they kept the stylus on the path the buzzer would sound did not convey the idea that the sound would cease when the stylus went off the path. If they seemed puzzled or remarked on this fact, they were told to come back on the path and the buzzer would sound. This usually was sufficient explanation to relieve the situation. In only two instances was the buzzer a noticeable distraction, and in these two cases each child watched it during only one trial.

If the child showed a tendency to pronouncedly accelerated speed with successive trials he was cautioned between trials to go slowly. In a few cases the caution to go slowly had no noticeable effect;

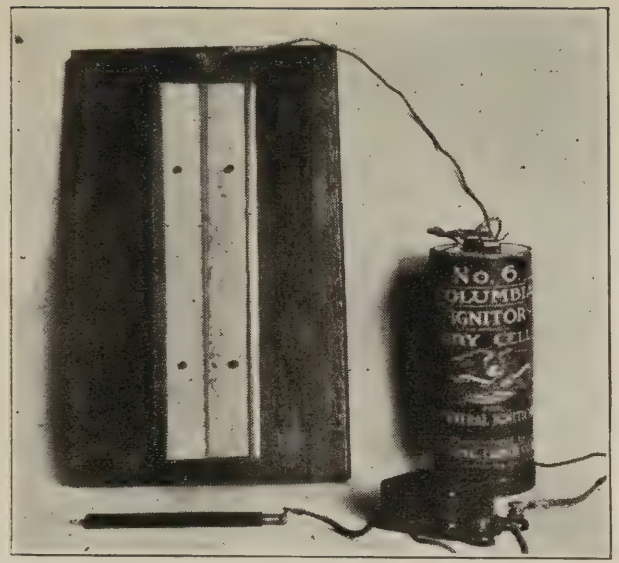

Fig. 1. In this tracing board the path is metal and is set flush with the glass. The stylus has a short point.

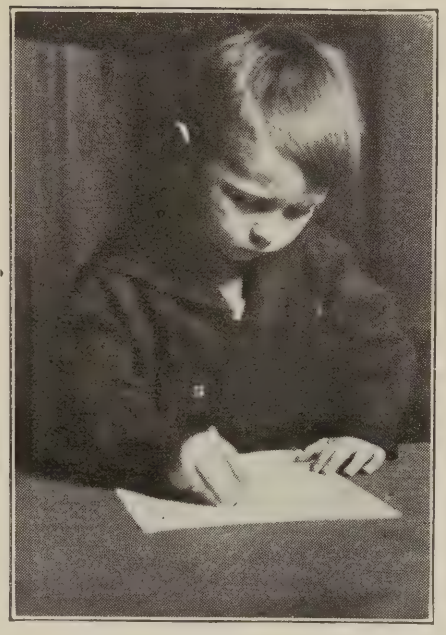

Fig. 3. Keeping between the lines is a serious business.

Fig. 2. This little girl tries pressure to help keep the stylus on the path.

in most cases, however, the result was a slowing down for the next following trial, but a speeding up again with the subsequent trial. The concept of slowness seems to be fairly well defined with these children, although a caution to go slowly is not kept in mind for more than one trial.

TRACING PATH EXPERIMENT

Materials

Some deficiencies in the use of the tracing board experiment as a means for detailed analysis of motor control soon became apparent: (1) A permanent record of the course of movement was not obtained. Such a record was desired for a detailed analysis of the types of lines made and the factors influencing these different types of performance. (2) The recording of the contacts on the tracing board required such close attention and concentration on the part of the experimenter that little opportunity was left for observation of the numerous other reactions of the child. (3) It was practically impossible to obtain an accurate score for the child whose movements were very rapid or very irregular.

The tracing path test was designed to meet these deficiencies and still be as comparable as possible to the tracing board test. Two lines were printed on a sheet of paper with the area between them the same as the area of the brass path of the tracing board (25 cm. long, 5 mm. wide at one end, and 1 mm. wide at the other end). The other conditions of the two experiments were as nearly identical as possible. A permanent and accurate record was obtained, and the scoring demanded of the experimenter while the experiment was in progress only the recording of the time for each trial.

Method of Conducting Experiment

The sheets of paper were fastened by thumb tacks to a piece of beaverboard the size of the table top. The sheets for the three trials in any one direction were fastened in a row along one edge of the board and when one direction was completed, the board was turned, bringing the sheets for the next direction into place. Each time, the child moved to a position directly in front of the sheet. The directions of movement and the order of giving them were the same as for the tracing board test. For those children in this study who were subjects for both the tracing board and the tracing path experiments the two tests were alternated, the tracing path following the tracing board, in this order:

First day, directions 1, 2, 3, 4, tracing board
Second day, directions 1, 2, 3, 4, tracing path
Third day, directions 5, 6, 7, 8, tracing board
Fourth day, directions 5, 6, 7, 8, tracing path

The instructions to the child were:

"See this pencil. I want you to make a mark right down the path with the pencil. [Experimenter demonstrated how to follow the path by drawing an imaginary line from 0 to 25.] Keep right in the path all the time."

Method of Scoring

Examination of the records showed that there were wide ranges of difference in the amount of excursion of the lines made by the children. The best method of scoring, therefore, seemed to be one that would take into account the total length of line and the relation of the part of the line within the path to the part that was out of the path. It was surprising to find that no accurate instrument was available for measuring the length of a crooked line. Chartometers on the market are graduated only in centimeters, which are too coarse units for the purpose, or they are graduated in the English system in eighths of an inch. Consequently various methods were tried out. Fine wire or thread bent to conform to the contour of the line and later straightened to be measured was impracticable because of the inaccuracy due to expansion and contraction on bending and unbending and because of the laboriousness of the task of measuring. Freeman,[31] in his handwriting experiments, in which the areas were much smaller, used fine pointed dividers with a ruler, or millimeter paper bent to conform to the line, but these methods also were laborious and impracticable for our purposes.

An aluminum wheel, 20 cm. in circumference and graduated in millimeters, with the edge milled to avoid slipping upon the paper, was finally constructed. For measuring the length of a line within the path the wheel was set down at zero and moved along the line until an intersection of the printed line was reached. The reading was noted, the wheel lifted and set down again at the point where the pencil line again intersected the printed line, and the measuring continued to the next intersection. This method gave the cumulative length of the line within the path and did away with the necessity for computation. Similarly, the length of the line outside the path was found.

Three checks were made to determine the accuracy of the measurements: (1) The total length of the line was measured and checked against the amount in path plus the amount off path. (2) Straight lines were measured and the measurements found to be exact. (3) One typical record was measured twenty times. The mean deviation was found to be 0.24 mm. and the range 2 mm., with fifteen of the twenty trials measuring exactly the same. One of the most difficult records to measure was then selected and measured five times, and the error was found to be not greater than for the typical record. A check was also made by remeasuring some records independently after several days' interval and comparing the results with those originally obtained. In no case was the difference greater than 2 mm.

The score for this test was obtained by dividing the length of the line in the path by the total length of the line.[5]

Response of Children

In an attempt to get the child's judgment on his product and his attitude toward his accomplishment, the experimenter asked, "Which of these do you think is best?" indicating the last three trials, and when the choice was made, "Why do you think that is best?" The three and four-year-old children selected a trial, but could seldom give any plausible reason for the selection, saying that they did not know or "Both are best," "They're all best," or "Because I writed them nice." The five-year-old children, although their selections did not always agree with the experimenter's judg-

5. When detailed analysis of the lines is not desired, a quicker method of scoring that will give practically the same percentage within the path may be used. The score is obtained by measuring with a rule the number of millimeters of the guideline opposite the parts of the child's line that are within the path and dividing this number by the number of millimeters of the guideline opposite the child's total line. This rule method was tried out and the scores checked against the scores by the wheel method for 359 cases (average of three trials each). In 61.8 per cent of the cases the results showed no difference in scores by the two methods; in 31.2 per cent there was a difference of 1 point; and in only one case was there a difference as large as 4 points:

Difference in scores, in points	Number of cases	
0	222	(61.8 per cent of 359)
1	112	(31.2 per cent of 359)
2	14	(3.9 per cent of 359)
3	10	(2.8 per cent of 359)
4	1	(0.3 per cent of 359)
	359	

ment, gave good reasons for their choice, such as, "Because it's the straightest line," "Because it's more straighter," "Doesn't have as many bumps in it," and "Because I went out of the path in the others. See." One child gave as his reason, "Because it's the last." When asked if the last is always the best, he replied, "Yes, because I have practiced on the others." It will be noted that although the instructions merely said to keep within the path, many children interpreted them to mean that they were to make as straight a line as possible.

CHAPTER IV

QUANTITATIVE ANALYSIS OF EXPERIMENTAL RESULTS

The results of the tracing board and tracing path tests on the control of hand and arm movements were studied with reference to reliability and to the influence on scores of age, sex, hand used, practice, and direction of movement. The relation of scores made on the two tests was also considered.

RELIABILITY OF TESTS

The reliability of the tracing board test was found by correlating the scores on one half of the directions against the scores on the other half. The groupings used were directions 1 ($\downarrow$), 4 ($\leftarrow$), 6 ($\searrow$), and 7 ($\nearrow$) against directions 2 ($\rightarrow$), 3 ($\uparrow$), 5 ($\swarrow$), and 8 ($\nwarrow$). These groupings were arrived at from two standpoints, the best pairing according to the order in which the tests were given, and the best pairing according to naturalness of movement from an adult *a priori* standpoint. The coefficient of correlation obtained by the product-moment method with these groupings for the fifty-four children from three to six years of age was .82 $\pm$ .04. When the Spearman-Brown prophecy formula[6] was applied for two tests, the reliability coefficient for the whole test became .90 $\pm$ .01.

The reliability of the tracing path test was computed by using the groupings of directions used with the tracing board. The correlation obtained by the product-moment method for ninety-four children from three to six years of age was .969 $\pm$ .004. When the Spearman-Brown prophecy formula was applied, the reliability coefficient for the whole test became .984 $\pm$ .002. This correlation was, of course, influenced by the range of ages included. In order to determine what the reliability would be within an age group, correlations were worked out by the rank method for three age groups and

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6. $r_x = \frac{Nr_1}{1 + (N-1)r_1}$

McCall, W. A. *How to Experiment in Education.* New York: Macmillan, 1923. Pp. 281 (p. 111).

the values transmuted into r. The reliability coefficients thus obtained were:

	r	Prophecy r
At three years	.785 ± .05	.876
At five years	.908 ± .02	.951
At six years	.875 ± .04	.933

The correlations between the various directions are discussed in connection with the relative difficulties of the eight directions.

AGE DIFFERENCES

Tables 1, 2, 3, and 4 give the points of first contact on the tracing board for each subject (average of the three trials), with the average and standard deviation for each direction separately for right and left hand performances. The average point of first contact for the eight directions for each child is also given.

It will be noted from these tables that while the differences in averages are small, each age group ranks higher than the preceding age group for each direction, except that the six-year group does not gain over the five-year group. Whether or not these differences with age are significant may be determined by finding the probable error of the difference of the means.[7]

It is found that the difference between the means for the children of three and five years is more than three times the probable error of the difference, and therefore significant, for each direction with the right hand, but that with the left hand the difference is not significant for any direction of movement except direction 7 (↗). The actual differences between the means and the probable errors of the differences for these two groups are as follows:

	Right hand		Left hand	
Direction	Actual difference	P.E. of difference	Actual difference	P.E. of difference
1 (↓)	4.3	.93	1.6	.79
2 (→)	5.9	.76	1.1	.48
3 (↑)	4.0	.95	1.5	.87
4 (←)	4.7	.46	1.1	.78
5 (↙)	4.3	1.08	0.2	.92
6 (↘)	5.0	1.06	1.5	.90
7 (↗)	5.0	1.43	2.7	.73
8 (↖)	6.5	1.74	0.2	.76

7. $\text{P.E.}_{\text{difference}} = \sqrt{\text{P.E.}^2_{M_1} + \text{P.E.}^2_{M_2}}$

McCall, W. A. *How to Experiment in Education.* New York: Macmillan, 1923. Pp. 281 (p. 151).

For the left hand, the scores for the four age groups are so close that the actual difference in the average of the eight directions between the three-year group and the six-year group is less than the difference between the three-year and four-year groups for the right hand. The left hand scores are at a lower level throughout than the right hand scores, the scores for all groups with the left hand approximating the scores for the three-year group with the right hand. This means that the disparity between right and left hand became increasingly greater with the increase in age.

The correlation of the average point of first contact on all directions with age was .88 ± .03 for boys and .53 ± .09 for girls from three to six years of age, indicating that the older child tended to go a longer distance than the younger child before making a contact.

Comparison of the averages with the results of Town[103] shows that the fifteen four-year-old children in this study are equal to and probably ahead of Town's forty-two five and six-year-old children. Her average point of first contact for direction 2 (→) with the right hand was 6.47, P.E. 2.48. Her records show a number of zero scores, which did not occur with the children in this experiment. The two tracing boards and methods of experiment were somewhat different, however, and for that reason the scores are not directly comparable.

The distance the child kept on the path, expressed in terms of percentage of the total length of the path, was used as another method of scoring the results. This method does not penalize unduly the child who goes off path early in his course but keeps on the path the rest of the way, as does the method of recording only the point of first contact. Tables 5, 6, 7, and 8 give these percentages for the individual children, with averages and standard deviations for the age groups.

In general, the results show the same tendencies as those for the point of first contact, that is, an increasingly higher score with age, and an increasingly greater difference between right and left hands.

The individual scores on the tracing path test with the right hand are given in Tables 9 to 15, with the averages and standard deviations for each half-year group. It will be seen from these tables that the scores of the six-year group are nearly double those of the three-year group, and that there is a general increase in scores from any half year to the next. This increase is greatest between three

TABLE 1
Individual Scores (Average of Three Trials) on Point of First Contact on the Tracing Board by Children of Three Years

Child	Age	Right hand									Left hand								
		Direction of movement								Average	Direction of movement								Average
	Years Months	1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖		1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	
F1	2– 7	5.7	5.3	8.3	2.0	2.7	11.7	4.0	6.7	5.8	3.0	3.7	10.3	2.3	2.0	1.5	4.0	3.0	3.7
M2	2– 9	4.0	3.0	5.0	3.7					3.9	3.3	7.3	5.0	2.3					4.5
M3	2–10	4.7	3.3	4.0	1.7	4.0	5.3	2.7	2.3	3.5	2.3	3.0			8.7	2.0	1.3	2.3	3.3
F5	2–11	11.0	6.5	6.7	2.7	5.7	5.0	7.7	2.3	6.0	6.0	4.0	9.0	14.3	13.3	5.2	8.7	6.0	8.3
M6	2–11	9.7	9.0	9.0	4.0	6.7	2.3	2.7	3.0	5.8	4.0	2.5	2.2	3.0	4.0	8.0	3.0	3.0	3.7
F7	3– 0	10.3	8.3	4.7	1.8	5.3	13.3	6.7	6.0	7.0	1.7	1.3	2.3	4.0	3.3	5.0	1.7	7.3	3.3
M7	3– 1	6.7	7.8	6.7	6.7					7.0									
M8	3– 1	6.5	5.7	6.3	7.7	7.3	8.0	2.8	6.0	6.3	1.5	1.5	3.0	2.3	6.3	5.3	4.3	7.3	3.9
M11	3– 2	9.0	3.3	6.0	6.0	7.0	2.3	8.0	3.0	5.6	6.0	5.0	6.0	7.3	5.3	4.0	5.3	3.7	5.3
F10	3– 2	9.7	7.0	10.0	2.7	4.7	3.7	5.3	6.7	6.2	3.3	4.7	5.7	2.0	3.5	4.7	8.3	6.3	4.8
F32	3– 3	3.5	4.0	5.0	8.0					5.1									
F11	3– 3	6.0	2.7	3.7	1.7	2.7	1.7	5.3	2.0	3.2	4.5	2.3	2.8	3.0	3.5	2.0	2.7	3.7	3.1
F12	3– 3	5.0	3.7	9.7	5.7	2.0	12.0	5.7	3.3	5.9	6.0	4.3	5.3	4.7	2.7	2.3	2.7	2.7	3.8
F13	3– 3	3.3	6.7	6.0	6.7	4.0	3.0	9.7	8.3	6.0	11.0	5.3	4.7	3.3					6.1
M13	3– 4	5.3	6.3	3.3	5.0					5.0	5.3	2.3	6.0	2.0					3.9
M17	3– 5	4.0				4.0	7.0	4.7	4.3	4.8	5.3	3.7	6.3	3.7	2.7	3.0	4.3	6.3	4.4
F16	3– 5	8.3	4.0	5.3	7.7	12.0	9.0	7.0	2.3	7.0	7.0	4.7	4.0	11.3	11.7	5.0	8.3	9.0	7.6
F17	3– 5	6.2	4.2	10.8	3.3	2.7	2.3	2.7	2.3	4.3	1.7	3.3	3.3	2.3	2.0	3.0	5.3	8.0	3.6
Average		6.6	5.3	6.5	4.5	5.0	6.2	5.4	4.2	5.5	4.5	3.7	5.1	4.5	5.3	3.9	4.6	5.3	4.6
S.D.		2.4	1.9	2.2	2.2	2.5	3.9	2.2	2.0		2.4	1.5	2.2	3.6	3.6	1.8	2.4	2.2	

TABLE 2

Individual Scores (Average of Three Trials) on Point of First Contact on the Tracing Board by Children of Four Years

Child	Age	Right hand									Left hand								
		Direction of movement								Average	Direction of movement								Average
	Years Months	1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖		1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	
M18	3– 6	9.3	8.3	5.3	5.0	7.0	2.0	4.7	4.3	5.7	3.3	1.7	4.0	4.3					3.3
M20	3– 6	4.0	2.7	4.7	7.3	8.7	5.3	4.7	13.3	6.3	2.3	8.0	6.7	4.3	16.7	7.7	7.7	7.0	7.6
F18	3– 6	11.5	6.0	6.0	12.3	13.0	12.3	9.7	10.7	10.2	5.2	7.3	3.0	3.0	4.7	2.7	3.3	4.3	4.2
F19	3– 7	9.7	10.3	4.0	5.7	9.7	2.3	3.7	3.0	6.0	1.3	4.0	4.7	2.3	2.7	2.7	3.7	3.0	3.0
M64	3– 7	6.7	9.3	12.0		3.7	7.3	7.5	3.7	7.2	2.0	3.0	4.0						3.0
M21	3– 7	10.0	5.0	6.0	12.7	9.7	2.0	7.3	4.3	7.1	2.0	5.0	1.7	4.7	2.3	2.7	2.8	2.3	2.9
F20	3– 7	17.3	8.3	6.3	10.7	11.7	9.0	8.7	5.3	9.7	2.7	8.0	5.3	8.3	7.0	5.3	3.3	8.3	6.0
M22	3– 8	10.3	5.3	10.0	12.0	7.8	2.8	7.3	10.0	8.2	3.2	10.3	3.0	5.3	13.0	4.3	10.3	3.7	6.6
M65	3–10	11.0	9.3	12.3	3.5					9.0									
F70	3–10	7.0	6.0	5.0	5.7					5.9									
F71	3–11	14.2	10.3	4.3	5.0					8.4	14.0	8.3	6.7	4.5					8.4
M30	4– 2	10.7	6.3	5.0	6.3					7.1	2.0	5.7	3.7	2.7					3.5
F33	4– 3	15.3	11.7	8.0	6.0					10.2	5.0	2.7	4.7	4.7					4.3
F34	4– 3	4.7	8.0	4.3	5.3	5.3	5.7	9.7	3.0	5.8	8.0	3.3	1.7	7.0	6.7	1.5	1.7	1.8	4.0
F35	4– 4	4.7	13.0	13.3	12.3	8.0	17.3	10.7	3.7	10.4	6.3	8.7	8.3	3.0	3.0	2.7	7.0	5.7	5.6
Average		9.8	8.0	7.1	7.8	8.5	6.6	7.4	6.1	7.8	4.4	5.8	4.4	4.5	7.0	3.7	5.0	4.5	4.8
S.D.		3.8	2.7	3.1	3.2	2.6	4.8	2.3	3.6		3.4	2.6	1.9	1.7	4.9	1.9	2.8	2.2	

TABLE 3
Individual Scores (Average of Three Trials) on Point of First Contact on the Tracing Board by Children of Five Years

Child	Age	Right hand									Left hand								
		Direction of movement								Average	Direction of movement								Average
	Years Months	1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖		1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	
F39	4– 7	11.7	7.3	13.0	9.5	4.3	8.0	4.3	4.3	7.8	7.7	2.7	9.7	6.3	5.0	4.0	6.3	5.0	5.8
M34	4– 7	16.3	11.7	4.3	7.7					10.0	4.0	6.0	1.7	2.7					3.6
M46	4– 7	9.2	16.2	13.2	7.5					11.5	2.0	6.0	2.7	6.0					4.2
F40	4– 8	15.0	5.8	9.2	10.3	12.0	11.0	6.7	11.0	10.1	4.7	3.2	4.7	2.5	2.3	2.3	7.7	3.0	3.8
F59	4– 8	15.0	9.3	16.7	10.0					12.8	11.2	6.7	6.7	4.0					7.2
F46	4–11	13.8	15.8	6.0	10.0	8.3	11.3	5.3	6.7	9.6	7.2	2.0	7.3	8.0	9.3	5.3	4.3	8.3	6.5
F51	5– 2	2.7	8.7	4.3	7.0	8.7	6.7	14.3	7.0	7.4	3.3	3.0	2.7	7.0	4.7	3.0	6.7	2.3	4.1
M44	5– 3	8.7	11.7	13.7	9.3	6.8	10.7	9.3	5.0	9.4	7.0	4.0	13.0	4.0	7.3	13.0	5.3	3.3	7.1
F57	5– 5	8.3	12.7	13.0	11.0	8.7	15.3	12.3	17.7	12.4	2.7	6.3	5.7	5.3	7.3	5.0	10.0	8.7	6.4
F58	5– 5	8.3	13.0	11.3	10.0	17.3	15.7	20.7	23.3	15.0	11.3	8.0	11.3	9.7	2.3	5.0	11.0	7.7	8.3
Average		10.9	11.2	10.5	9.2	9.4	11.2	10.4	10.7	9.9	6.2	4.8	6.6	5.6	5.4	5.4	7.3	5.5	5.7
S.D.		4.0	3.3	4.1	1.3	3.9	3.1	5.4	6.7		3.2	1.9	3.6	2.2	2.5	3.3	2.2	2.5	

TABLE 4

Individual Scores (Average of Three Trials) on Point of First Contact on the Tracing Board by Children of Six Years

Child	Age	Right hand									Left hand								
		Direction of movement								Average	Direction of movement								Average
	Years Months	1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖		1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	
M48	5– 6	7.3	13.7	8.0	6.0	10.7	15.0	15.3	7.7	10.5	7.8	9.2	6.3	5.5	2.7	10.3	3.7	6.7	6.5
M50	5– 6	12.3	8.7	7.0	9.3	5.0	11.3	8.7	4.0	8.3	2.0	3.0	2.7	4.7	5.7	2.0	9.7	3.0	4.1
M52	5– 6	7.7	10.7	7.0	7.3	14.7	13.7	16.7	4.7	10.3	6.0	6.7	15.7	9.0	6.0	5.3	11.3	7.7	8.5
M53	5– 6	12.0	11.7	7.3	8.0	16.3	15.7	5.0	9.0	10.6	10.7	2.7	3.8	3.7	11.0	6.0	6.7	7.3	6.5
M54	5– 7	22.0	11.3	3.3	7.7	17.5	7.3	6.0	11.3	10.8	1.7	4.0	10.3	9.0	8.7	5.3	8.3	10.3	7.2
F60	5– 7	8.7	15.3	4.0	7.7	12.0	10.7	14.2	9.0	10.2	2.3	2.3	5.0	2.0	3.3	3.0	9.7	8.3	4.5
M60	5– 9	17.3	21.7	16.0	14.7					17.4									
F63	5– 9	3.7	4.0	9.7	6.0	3.0	2.3	6.0	6.7	5.2	4.7	8.0	7.0	6.0	2.7	6.0	5.0	5.7	5.6
F64	5– 9	4.0	7.3	9.3	9.7	17.8	9.3	20.0	15.7	11.6	6.2	5.0	5.3	2.2	6.7	5.0	10.7	19.3	7.6
M55	5–11	6.0	12.0	8.0	13.0	7.7	14.0	9.3	9.7	10.0	3.7	9.0	2.0	6.0	6.7	2.7	8.7	4.3	5.4
F68	6– 4	10.0	7.7	6.0	4.7	8.0	11.3	5.7	9.2	7.8	3.7	6.0	6.0	6.3	2.3	5.0	11.3	7.0	6.0
Average		10.1	11.3	7.8	8.6	11.3	11.1	10.7	8.7	10.2	4.9	5.6	6.4	5.4	5.6	5.1	8.5	8.0	6.2
S.D.		5.3	4.5	3.2	2.9	5.0	3.8	5.1	3.2		2.7	2.5	3.8	2.3	2.7	2.2	2.5	4.2	

TABLE 5

Individual Scores (Average of Three Trials) on Percentage of Line within Path on the Tracing Board by Children of Three Years

Child	Age	Right hand									Left hand								
		Direction of movement								Average	Direction of movement								Average
	Years Months	1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖		1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	
F1	2– 7	73	51	75	57	80	73	63	81	69.1	50	64	73	63	57	32	42	37	52.3
M2	2– 9	63	44	61	61					57.3	53	63	55	31					50.4
M3	2–10	55	20	33	47	72	63	67	79	54.5	51	34			73	58	62	72	58.3
F5	2–11	92	78	84	79	73	45	79	57	73.4	73	79	69	75	95	77	81	66	76.9
M6	2–11	62	77	81	43	73	39	51	73	62.4	62	33	51	75	75	85	56	68	63.1
F7	3– 0	55	61	47	11	71	85	53	59	55.3	47	56	37	55	63	41	44	46	48.6
M7	3– 1	78	84	86	87					83.8									
M8	3– 1	57	79	82	55	65	59	56	54	63.4	60	40	55	59	74	70	73	70	62.6
M11	3– 2	77	63	82	61	67	53	73	42	64.8	79	57	63	69	75	63	77	71	69.3
F10	3– 2	66	60	79	52	72	38	69	55	61.4	53	64	35	55	51	37	55	44	49.3
F32	3– 3	68	71	48	72					64.8									
F11	3– 3	72	76	70	55	57	69	59	55	64.1	69	62	59	70	79	69	83	72	70.4
F12	3– 3	92	87	92	78	51	88	63	88	79.9	80	69	71	61	69	57	64	54	65.6
F13	3– 3	61	57	71	65	63	63	63	84	65.9	79	53	67	67					66.5
M13	3– 4	53	54	31	56					48.5	77	77	58	40					63.0
M17	3– 5	33	68			69	72	56	81	63.2	77	57	73	55	76	65	62	69	66.8
F16	3– 5	71	70	51	59	84	80	78	73	70.8	65	75	67	85	94	91	87	91	81.9
F17	3– 5	92	75	90	77	59	52	51	73	71.1	79	72	58	48	77	69	78	69	68.8
Average		67.8	65.3	68.4	59.7	68.3	62.8	62.9	68.1		65.9	59.7	59.4	60.5	73.7	62.6	66.5	63.8	
S.D.		14.9	15.9	19.0	16.9	8.5	15.5	9.0	13.6		11.8	13.8	11.4	13.6	11.9	17.0	14.1	14.0	

TABLE 6

Individual Scores (Average of Three Trials) on Percentage of Line within Path on the Tracing Board by Children of Four Years

Child	Age	Right hand									Left hand								
		Direction of movement								Average	Direction of movement								Average
	Years Months	1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖		1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	
M18	3– 6	88	69	91	65	73	56	78	71	73.9	76	70	69	54					67.3
M20	3– 6	87	59	52	66	70	68	63	87	69.0	72	71	66	51	94	77	87	85	75.4
F18	3– 6	91	83	86	81	95	74	88	75	84.1	80	83	75	75	72	59	75	77	74.5
F19	3– 7	75	73	90	49	53	36	55	42	59.1	57	71	64	36	53	52	37	35	50.6
M64	3– 7	86	69	82		60	39	88	54	68.3	50	37	20						35.7
M21	3– 7	58	59	75	82	51	41	69	65	62.5	61	44	59	67	76	61	60	40	58.5
F20	3– 7	92	89	92	97	93	73	76	75	85.9	70	88	87	81	84	79	68	81	79.8
M22	3– 8	91	70	88	95	85	94	85	77	85.7	77	62	54	74	91	75	82	79	74.3
M65	3–10	81	79	95	24					69.8									
F70	3–10	71	69	82	27					62.3									
F71	3–11	91	74	79	67					77.8	91	89	89	87					89.0
M30	4– 2	93	89	93	86					90.3	85	89	75	71					80.0
F33	4– 3	80	59	87	55					70.3	74	79	77	83					78.3
F34	4– 3	53	65	77	71	82	77	69	85	72.4	75	49	78	57	83	64	67	61	66.8
F35	4– 4	89	84	87	86	93	96	86	91	89.0	89	76	92	83	83	68	73	83	80.9
Average		81.7	72.7	83.7	67.9	75.5	65.4	75.7	72.2		73.6	69.8	69.6	68.2	79.5	66.9	68.6	67.6	
S.D.		12.1	10.0	10.4	22.0	15.8	20.7	10.9	14.4		11.6	16.6	18.0	15.0	12.0	9.0	14.4	18.7	

TABLE 7

Individual Scores (Average of Three Trials) on Percentage of Line within Path on the Tracing Board by Children of Five Years

Child	Age	Right hand									Left hand								
		Direction of movement								Average	Direction of movement								Average
	Years Months	1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖		1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	
F39	4– 7	93	92	88	73	83	85	66	90	83.8	83	84	88	67	69	45	92	61	73.6
M34	4– 7	83	83	92	81					84.8	49	65	53	57					56.0
M46	4– 7	93	94	95	79					90.3	67	86	81	81					78.8
F40	4– 8	95	84	93	89	89	81	84	85	87.5	76	81	77	89	54	57	72	59	70.6
F59	4– 8	97	83	97	89					91.5	69	72	57	67					66.3
F46	4–11	91	95	85	89	75	76	65	86	82.8	71	65	68	67	85	79	79	86	75.0
F51	5– 2	79	82	83	71	89	81	94	70	81.1	79	67	43	77	55	47	75	41	60.5
M44	5– 3	84	89	88	65	83	72	83	75	79.9	63	65	84	60	67	66	81	57	67.9
F57	5– 5	95	91	91	89	89	97	98	87	92.1	67	74	89	59	62	55	87	56	68.6
F58	5– 5	85	94	95	91	93	87	99	99	92.9	85	82	88	81	57	77	88	56	76.8
Average		89.5	88.7	90.7	81.6	85.9	82.7	84.1	84.6		70.9	74.1	72.8	70.5	64.1	60.9	82.0	59.4	
S.D.		5.9	4.9	4.4	8.8	5.5	7.5	13.1	8.9		10.1	8.1	15.8	10.3	10.1	12.6	6.8	12.4	

TABLE 8

Individual Scores (Average of Three Trials) on Percentage of Line within Path on the Tracing Board by Children of Six Years

Child	Age	Right hand									Left hand								
		Direction of movement								Average	Direction of movement								Average
	Years Months	1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖		1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	
M48	5– 6	89	91	88	77	71	79	95	85	84.4	85	87	79	59	73	73	78	53	73.4
M50	5– 6	85	88	91	87	86	90	93	87	88.4	75	83	81	79	81	69	88	71	78.4
M52	5– 6	81	91	79	85	91	93	91	89	87.5	84	83	87	83	93	71	89	77	83.4
M53	5– 6	87	89	93	85	86	90	91	90	88.9	85	82	90	83	85	75	89	74	82.9
M54	5– 7	96	78	71	69	86	64	80	83	78.4	69	72	79	55	61	43	59	73	63.9
F60	5– 7	71	91	77	85	87	86	92	80	83.6	75	79	71	69	67	69	85	84	74.9
M60	5– 9	91	99	91	91					93.0									
F63	5– 9	80	67	82	57	76	83	88	63	74.5	59	77	80	82	62	57	73	54	68.0
F64	5– 9	81	88	89	80	95	95	96	99	90.4	65	81	70	80	84	77	91	97	80.6
M55	5–11	75	79	69	81	75	80	95	90	80.5	77	71	73	60	77	63	77	65	70.4
F68	6– 4	74	92	67	55	69	83	71	76	73.4	60	67	71	56	65	81	79	75	69.3
Average		82.7	86.6	81.6	77.4	82.2	84.3	89.2	84.2		73.4	78.2	78.1	70.6	74.8	67.8	80.8	72.3	
S.D.		7.4	8.4	9.1	11.5	8.4	8.5	7.5	9.2		9.4	6.0	6.5	11.4	10.4	10.5	9.3	12.4	

TABLE 9
Individual Scores (Average of Three Trials) on the Tracing Path with the Right Hand by Children of Three Years

Child	Age (Years Months)	Direction of movement 1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	Average
M1	2– 9	47	53	42	48	40	45	43	38	44.5
M2	2– 9	65	45	23	40					43.3
M3	2–10	37	31	34	33	59	55	52	44	43.1
F4	2–10	66	23	48	38	62	55	73	70	54.4
M4	2–11	32	23	40	46					35.2
F5	2–11	26	25	38	47	41	28	27	39	33.9
M5	2–11	52	33	31	24	37	35	22	24	32.3
F6	2–11	55	45	55	38	69	56	45	61	53.0
M6	2–11	47	37	36	39	46	38	34	50	40.9
F7	3– 0	37	40	33	37	56	66	40	47	44.5
M7	3– 1	77	53	78	81					72.3
M8	3– 1	58	49	36	53	37	33	50	39	44.4
M9	3– 1	94	92	76	81					85.8
F8	3– 1	51	48	27	38	70	53	76	44	50.9
F9	3– 2	27	41	41	33	55	36	51	53	42.1
M10	3– 2	43	49	41	46	37	57	48	36	44.6
M11	3– 2	43	32	42	35	54	37	59	72	46.8
F10	3– 2	51	49	33	54	45	35	53	43	45.4
Average		50.4	42.7	41.9	45.0	50.6	44.9	48.1	47.1	
S.D.		16.9	15.4	14.4	14.6	11.3	11.3	14.6	12.8	

and four years of age and least between five and one-half and six years, where the scores near perfection. The variability of the scores, as measured by the standard deviations, is greater for the younger children than for the older children.

Only the superior children less than two years and nine months of age in this group understood the task sufficiently well to make scores. There were three such girls, aged two years and three months, two years and seven months, and two years and seven months, respectively, who succeeded; the third one of these had previously failed at two years and three months. Four other children less than three years of age failed to make scores. Their ages were as follows:

Boy, 2 years, 3 months: failure again at 2 years, 6 months
Boy, 2 years, 6 months: no second attempt
Girl, 2 years, 7 months: success at 2 years, 11 months
Boy, 2 years, 10 months: success at 3 years, 2 months

The coefficient of correlation between age and the average score on the eight directions on the tracing path for the entire group of

TABLE 10
Individual Scores (Average of Three Trials) on the Tracing Path with the Right Hand by Children of Three and One-Half Years

Child	Age (Years Months)	Direction of movement								Average
		1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	
M12	3– 3	40	20	45	57	54	45	57	53	46.4
F11	3– 3	47	70	73	54	47	61	55	46	56.6
F12	3– 3	60	47	31	50	53	61	54	65	52.6
F13	3– 3	52	42	57	58	55	54	51	59	53.5
M13	3– 4	69	73	62	50					63.5
M14	3– 4	61	46	37	22	41	24	27	40	37.3
F14	3– 4	60	52	46	59					54.3
M15	3– 5	76	69	70	63	71	71	47	59	65.8
M16	3– 5	36	26	31	40					33.2
F15	3– 5	30	68	35	44	39	77	72	48	51.6
M17	3– 5	49	41	37	56	69	69	47	72	55.0
F16	3– 5	65	59	36	50	56	56	71	75	58.5
F17	3– 5	80	62	78	69	70	59	61	73	69.0
M18	3– 6	80	49	61	67					64.3
M19	3– 6	42	51	48	57					49.5
M20	3– 6	49	38	77	56	67	76	72	79	64.3
F18	3– 6	89	78	81	65	43	61	37	43	62.1
F19	3– 7	61	62	66	42	32	40	55	42	50.0
M21	3– 7	42	27	27	21	54	60	47	63	42.6
F20	3– 7	74	76	70	61	62	62	48	83	67.0
F21	3– 7	70	48	52	31	85	61	63	56	58.3
F22	3– 7	84	90	73	87					83.5
F24	3– 8	75	37	43	44	72	46	40	65	52.8
F23	3– 8	65	38	36	35					43.5
F25	3– 8	54	46	65	60	83	51	58	59	59.5
M23	3– 8	86	80	55	49					67.5
M22	3– 8	83	90	95	79	83	89	69	80	83.5
M24	3– 8	69	53	57	57	80	62	73	63	64.3
Average		62.4	54.9	55.1	53.0	60.8	59.3	55.2	61.2	
S.D.		16.0	18.4	17.7	14.7	15.4	13.9	12.4	12.9	

children was .81 ± .03 for boys and .82 ± .03 for girls, indicating that the older child made a higher score than the younger child.

SEX DIFFERENCES

For determining any possible differences in scores on the tracing board that might be due to sex, the averages of the scores with the right hand and the standard deviations were calculated for all boys and for all girls for each direction of movement, since the number of children was too small for subdivision of the age groups by sexes. Table 16, which gives these average scores and standard deviations, shows that by either method of scoring there are no differences in scores that can be attributed to sex. Neither does it appear from

TABLE 11

Individual Scores (Average of Three Trials) on the Tracing Path with the Right Hand by Children of Four Years

Child	Age (Years Months)	Direction of movement 1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	Average
F26	3– 9	85	82	67	71					76.3
M25	3– 9	71	79	74	59	66	79	71	56	69.4
M26	3– 9	55	45	48	50	68	74	52	54	55.8
F27	3– 9	45	32	47	38	56	74	62	73	53.4
F28	3–10	94	92	76	81					85.8
M27	3–10	73	64	60	49					61.5
F29	3–10	88	64	68	56					69.0
M28	4– 0	85	63	74	62					71.0
M29	4– 0	78	78	47	51					63.5
F30	4– 1	70	87	90	82	77	75	82	77	80.0
F31	4– 1	94	91	95	85					91.3
M30	4– 2	86	82	95	68					82.8
Average		77.0	71.6	70.1	62.7	66.8	75.5	66.8	65.0	
S.D.		14.5	17.8	18.0	14.3	7.5	1.1	11.1	10.1	

TABLE 12

Individual Scores (Average of Three Trials) on the Tracing Path with the Right Hand by Children of Four and One-Half Years

Child	Age (Years Months)	Direction of movement 1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	Average
F32	4– 3	83	73	81	87	90	77	74	89	81.8
F33	4– 3	97	72	77	76					80.5
F34	4– 3	64	38	68	53	51	69	64	52	57.4
M31	4– 4	91	89	93	88					90.5
F35	4– 4	87	88	86	93	94	78	78	83	85.9
F36	4– 5	82	90	87	67	94	93	91	90	86.8
M32	4– 6	95	82	87	78	88	67	78	70	81.4
M33	4– 6	80	82	71	79	65	79	75	77	76.0
F37	4– 7	93	85	94	87					89.8
F38	4– 7	88	84	74	74	80	70	69	66	75.6
F39	4– 7	80	74	67	73	44	61	63	81	67.9
M34	4– 7	89	86	75	82					83.0
F40	4– 8	68	58	78	68	69	61	58	73	66.6
F41	4– 8	94	69	69	66	97	89	88	84	82.0
F42	4– 8	84	79	89	79	86	87	89	88	85.2
Average		85.0	76.6	79.7	76.7	78.0	75.5	75.2	77.5	
S.D.		9.1	13.4	8.8	10.1	17.4	10.5	10.6	11.1	

TABLE 13
Individual Scores (Average of Three Trials) on the Tracing Path with the Right Hand by Children of Five Years

Child	Age	Direction of movement								Average
	Years Months	1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	
F44	4– 9	91	78	67	84	90	92	91	96	86.1
F43	4– 9	84	88	73	87					83.0
F45	4–10	80	71	61	61	74	85	65	69	70.8
M35	4–11	57	60	55	67					59.8
M36	4–11	94	92	91	89	90	100	81	90	90.9
M37	4–11	91	81	85	62					79.8
F46	4–11		79	84	85	71	87	76	82	80.6
F47	4–11	91	84	82	90					86.8
F48	5– 0	94	87	84	93	89	94	86	85	89.0
M38	5– 0	87	87	83	89	91	91	84	87	87.4
M39	5– 0	37	36	57	68					49.8
F49	5– 1	89	91	90	88	91	90	94	88	90.1
M40	5– 1	98	93	94	90					93.8
F50	5– 1	99	97	99	89					96.0
M41	5– 2	83	84	89	85	91	83	86	79	85.0
M42	5– 2	93	82	81	82	95	75	94	89	86.4
F51	5– 2	75	80	87	73	76	80	91	81	80.4
Average		83.9	80.6	80.1	81.3	85.8	87.7	84.8	84.6	
S.D.		15.6	14.0	12.6	10.3	8.2	6.9	8.6	7.0	

the standard deviations that one sex is more variable than the other in scores.

For determining sex differences in scores on the tracing path, the average score for each direction of movement for each sex was computed for each age. Standard deviations were calculated for the three and five-year age groups, since the largest number of cases fell in these two groups. Table 17 shows that there is no consistent tendency for one sex to be ahead of the other. The boys are ahead on some directions and the girls are ahead on others. Since year groupings are rather coarse for such young children, however, it seemed wise to investigate the array of ages within a group. The average age for the four-year-old girls was found to be 2.2 months greater than for the four-year-old boys, the average age for the six-year-old girls to be 2.6 months greater than for the six-year-old boys, and the average ages for the three and five-year-old boys and girls to be the same. Two months might mean sufficient growth at these early ages to influence the scores, and the two sexes were therefore divided into groups in which the ages were

TABLE 14

Individual Scores (Average of Three Trials) on the Tracing Path with the Right Hand by Children of Five and One-Half Years

Child	Age (Years Months)	Direction of movement 1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	Average
M44	5– 3	85	92	71	62	84	83	93	83	81.6
F52	5– 3	97	92	90	93	89	90	94	85	91.3
M43	5– 3	92	81	80	82					83.8
F53	5– 3	99	91	96	91	91	86	90	96	92.5
M46	5– 4	80	75	85	73	85	86	88	81	81.6
F54	5– 4	99	99	95						97.7
F55	5– 5	94	93	95	96	96	90	95	96	94.4
M47	5– 5	96	87	90	80	94	90	90	93	90.0
F56	5– 5	84	83	77	77	84	86	79	78	81.0
F57	5– 5	96	99	99	99	87	83	83	85	91.4
F58	5– 5	89	99	97	88	96	93	96	94	94.0
F59	5– 5	82	68	82	56					72.0
M45	5– 6	98	98	93	90	93	92	90	93	93.4
M48	5– 6	68	87	95	87	77	86	95	88	85.4
M49	5– 6	91	80	84	86					85.3
M50	5– 6	94	93	92	93	98	93	90	95	93.5
M51	5– 6	91	83	95	86					88.8
M52	5– 6	82	96	93	87	87	96	96	96	91.6
M53	5– 6	94	93	100	92	88	87	91	86	91.4
M54	5– 7	81	67	75	80	77	89	79	88	79.5
F60	5– 7	81	80	95	84	91	90	97	91	88.6
F61	5– 7	100	92	89	87	94	91	84	91	91.0
F62	5– 7	96	91	94	81	97	99	99	94	93.9
Average		90.0	87.9	89.6	84.1	89.3	89.4	90.5	89.6	
S.D.		8.0	9.1	7.8	10.0	6.2	4.2	5.9	5.2	

TABLE 15

Individual Scores (Average of Three Trials) on the Tracing Path with the Right Hand by Children of Six Years

Child	Age (Years Months)	Direction of movement 1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	Average
F63	5– 9	73	76	77	78	87	73	87	73	78.0
F64	5– 9	96	86	91	93	94	94	99	96	93.6
F65	5–10	72	74	72	75					73.3
M55	5–11	86	83	59	85	91	92	95	87	84.8
M56	5–11	99	87	96	84	92	91	84	97	91.3
M57	5–11	100	100	100	99	99	100	99	99	99.5
M58	6– 1	94	96	83	90	87	94	88	91	90.4
F66	6– 1	98	97	96	92	99	99	97	96	96.8
F67	6– 2	100	99	99	97	98	96	95	98	97.8
Average		90.9	88.7	85.9	88.1	93.4	92.4	93.0	92.1	
S.D.		10.6	9.3	13.4	7.8	4.7	7.9	5.4	8.1	

TABLE 16

Average Scores and Standard Deviations on Point of First Contact and on Percentage of Line within Path on the Tracing Board by Boys and by Girls

	Number of children	Direction of movement															
		1 ↓		2 →		3 ↑		4 ←		5 ↙		6 ↘		7 ↗		8 ↖	
		Score	S.D.	Score	S.D.	Score	S.D.	Score	S.D.	Score	S.D.	Score	S.D.	Score	S.D.	Score	S.D.
Point of first contact																	
Boys	25	9.2	4.3	8.9	4.4	7.6	3.5	7.5	3.2	8.5	4.0	7.8	4.8	7.2	3.9	6.2	3.2
Girls	29	8.8	4.2	8.0	3.5	7.7	3.4	6.9	3.3	7.9	4.1	8.8	4.6	8.6	4.7	7.8	5.2
Percentage of line within path																	
Boys	25	77.1	15.7	74.6	13.8	78.7	17.7	70.7	17.3	74.3	10.4	67.8	18.1	77.3	14.3	75.4	13.8
Girls	29	80.2	12.3	77.3	12.2	80.5	13.1	66.7	19.6	77.9	13.5	75.1	16.7	75.2	14.7	76.2	12.7

TABLE 17
Average Scores and Standard Deviations on the Tracing Path by Boys and by Girls from Three to Six Years of Age

Age, years	Number of children	Direction of movement																Average Score
		1 ↓		2 →		3 ↑		4 ←		5 ↙		6 ↘		7 ↗		8 ↖		
		Score	S.D.	Score	S.D.	Score	S.D.	Score	S.D.	Score	S.D.	Score	S.D.	Score	S.D.	Score	S.D.	
Boys																		
3	14	54.6	12.7	45.1	14.0	43.9	14.9	46.2	15.2	49.5	12.1	46.3	14.4	44.2	11.3	47.9	14.4	47.2
4	9	68.8		58.4		67.5		57.6		69.6		73.3		64.0		65.8		65.6
5	11	89.1	6.2	86.6	5.8	83.3	7.5	80.8	7.8	87.6	8.3	84.6	9.0	85.9	6.0	84.2	7.2	85.3
6	9	88.6		89.1		88.1		88.5		88.4		92.0		90.7		91.8		89.7
Matched	23	67.7	19.9	61.6	24.8	63.6	21.7	61.4	21.1	69.6	17.8	70.2	20.0	64.0	19.6	68.1	19.2	65.8
Girls																		
3	16	50.6	15.0	49.9	14.1	47.5	16.0	49.3	10.7	55.8	10.1	54.4	13.0	56.6	13.1	53.3	12.5	52.2
4	13	73.1		63.6		70.2		61.4		69.9		65.5		62.6		67.6		66.7
5	18	87.3	8.2	81.9	11.0	82.5	11.2	80.2	12.2	83.5	12.8	83.7	9.9	82.7	11.9	83.9	8.7	83.2
6	9	92.0		88.1		91.6		86.4		92.8		91.5		94.6		90.6		91.0
Matched	23	67.3	23.5	61.1	23.6	63.3	22.6	61.3	21.5	69.6	17.7	65.3	19.7	65.7	18.7	66.7	17.5	65.0

matched to the exact month. There were forty-six boys and girls whose birthdays were identical to the month who had scores on all eight directions. The average score for these boys was 65.8, for the girls 65.0. The averages, which are given in Table 17, are almost identical for the boys and girls for each direction. It would seem, therefore, that in the scores on this test there are no real sex differences.

PERFORMANCE WITH RIGHT AND LEFT HANDS

When the right hand was used, the child did not usually have difficulty in attaining a fairly good grasp of the stylus or pencil in an ordinary writing position. When the left hand was used, this adjustment appeared to be more difficult. In the experiments with the left hand the stylus or pencil was given to the child so that he took it naturally in the left hand, but he almost invariably transferred it to his right hand. It became necessary in many cases to readjust it to the left hand before every trial. Verbal protest at the use of this hand was rare in the younger children, but there were sometimes movements of confusion and consequent self-consciousness. The older children often voiced their objections, remarking that it was "hard" or giving some reason why the right hand was preferable. If the performance did not progress satisfactorily to the child, he sometimes shifted the stylus or pencil during a trial or stopped to readjust it with his right hand.

Mention has already been made of the lower level of scores on the tracing board with the left hand and of the increasing difference between scores with right and left hands as age increases. There are only a few cases in which a child's left hand average exceeds his right hand average, although cases in which the left hand score exceeds the right hand for a particular direction are not rare. Except for two directions, direction 5 (↙) and 8 (↖), for the three-year group, there is no direction of movement for any age on which the group average on point of first contact (Table 5) for the left hand exceeds that for the right hand, and even in these two instances the differences can not be considered significant. Presumably, any advantages due to transfer of training or to practice should have gone to the left hand scores, since the tests with the left hand came later than those with the right hand.

The correlation between the combined average of the points of first contact for all eight directions with the right hand and this

combined average with the left hand was .52 ± .08, when the entire group of children was included. When age was held constant by means of partial correlation, the correlation between right and left hand scores lost its significance, dropping to .15 ± .10. Apparently there was no relationship between performance with the right and left hands, apart from that influenced by age. The number of children at any one age was too small for reliable correlation within an age group.

Forty-one children were given the tracing path test with the left hand as well as with the right hand. For purposes of comparison Tables 18 to 21 give their individual scores, by age groups, with the left hand and with the right hand. There are lower average scores for the left hand than for the right hand for the various directions of movement, the difference between the two hands being less at three years than at any other age.

When individual children's records on the tracing path for the two hands are compared, it is found that the scores for the left hand exceed those for the right hand for some specific directions, although which the directions are depends upon individual differences in the children. In this group of forty-one children there are more cases on direction 2 (→) in which the score with the left hand exceeds the score with the right hand than on any other direction. When the directions are ranked for the age groups, directions 2 (→) and 7 (↗) rank markedly higher than any other direction for the left hand. It is probably justifiable to conclude then that directions 2 (→) and 7 (↗) were the easiest movements for these children to make with the left hand. It is not justifiable, however, to conclude that direction 4 (←) with the right hand is comparable with direction 2 (→) with the left hand. In fact, judging from the rankings for the age groups, direction 4 seems to be a particularly difficult one for either hand.

The correlation between the average score on the tracing path with the right hand and the average score with the left hand was .74 ± .05, when the group included children from three to six years of age. When age was held constant by the partial correlation method, the correlation was .40 ± .09, indicating that a child who ranked high in score with his right hand tended also to rank high in score with his left hand. The correlation between age and the average score with the left hand was .69 ± .06 for children from

TABLE 18

Individual Scores (Average of Three Trials) on the Tracing Path with Right and Left Hands by Children of Three Years

Child	Age	Right hand									Left hand								
		Direction of movement								Average	Direction of movement								Average
	Years Months	1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖		1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	
F3	2– 7	51	74	75	69	51	48	66	36	58.8	48	56	42	49					48.8
M3	2–10	37	31	34	33	59	55	52	44	43.1	50	39	40	39	45	29	43	42	40.9
F5	2–11	26	25	38	47	41	28	27	39	33.9	49	27	23	39	48	38	60	39	40.4
F7	3– 0	37	40	33	37	56	66	40	47	44.5	54	37	36	47	43	38	32	24	38.9
M6	3– 0	47	37	36	39	46	38	34	50	40.9	41	58	26	30					38.8
M8	3– 1	58	49	36	53	37	33	50	39	44.4	41	31	36	21	41	37	43	38	36.0
M11	3– 2	43	32	42	35	54	37	59	72	46.8	29	35	28	44	30	40	41	49	37.0
F10	3– 2	51	49	33	54	45	35	53	43	45.4	44	44	47	48	17	45	49	39	41.6
F11	3– 3	47	70	73	54	47	61	55	46	56.6	58	59	37	58	51	27	47	53	48.8
F12	3– 3	60	47	31	50	53	61	54	65	52.6	63	51	51	48	37	36	25	46	44.6
F13	3– 3	52	42	57	58	55	54	51	59	53.5	56	45	56	51					52.0
M17	3– 5	49	41	37	56	69	69	47	72	55.0	52	46	46	14	56	66	46	48	46.8
F16	3– 5	65	59	36	50	56	56	71	75	58.5	53	45	51	54	65	38	63	50	51.6
F17	3– 5	80	62	78	69	70	59	61	73	69.0	68	46	47	57	69	60	69	55	58.9
Average		50.2	47.0	45.6	50.2	52.7	50.0	51.4	54.2		50.4	44.2	40.4	42.3	45.6	41.2	47.0	43.9	

TABLE 19

Individual Scores (Average of Three Trials) on the Tracing Path with Right and Left Hands by Children of Four Years

Child	Age	Right hand									Left hand								
		Direction of movement								Average	Direction of movement								Average
	Years Months	1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖		1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	
M18	3– 6	80	49	61	67					64.3	67	49	37	44					49.3
M20	3– 6	49	38	77	56	67	76	72	79	64.3	53	59	54	65	59	94	79	64	65.9
F18	3– 6	89	78	81	65	43	61	37	43	62.1	53	72	55	51	40	37	55	48	51.4
F19	3– 7	61	62	66	42	32	40	55	42	50.0	47	54	45	39	56	69	48	46	50.5
M21	3– 7	42	27	27	21	54	60	47	63	42.6	25	32	38	13	26	18	28	18	24.8
F20	3– 7	74	76	70	61	62	62	48	83	67.0	61	61	55	48	36	60	49	24	49.3
M22	3– 8	83	90	95	79	83	89	69	80	83.5	83	69	69	69	68	79	79	88	75.5
F33	4– 3	97	72	77	76					80.5	73	65	64	65					66.8
F34	4– 3	64	38	68	53	51	69	64	52	57.4	44	48	43	36	63	52	55	49	48.8
F35	4– 4	87	88	86	93	94	78	78	83	85.9	80	92	81	81	65	50	58	64	71.4
Average		72.6	61.8	70.8	61.3	60.7	66.8	58.7	65.6		58.6	60.1	54.1	51.1	51.6	57.3	56.3	50.1	

TABLE 20
Individual Scores (Average of Three Trials) on the Tracing Path with Right and Left Hands by Children of Five Years

Child	Age	Right hand									Left hand								
		Direction of movement								Average	Direction of movement								Average
	Years Months	1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖		1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	
F39	4– 7	80	74	67	73	44	61	63	81	67.9	49	53	57	55					53.5
F40	4– 8	68	58	78	68	69	61	58	73	66.6	58	76	72	61	60	54	73	64	64.8
F46	4–11		79	84	85	71	87	76	82	80.6	75	70	75	61					70.3
F51	5– 2	75	80	87	73	76	80	91	81	80.4	67	85	79	66	68	81	77	81	75.5
M44	5– 3	85	92	71	62	84	83	93	83	81.6	50	66	67	56	60	59	82	58	62.3
F57	5– 5	96	99	99	99	87	83	83	85	91.4	74	89	89	85	79	87	88	88	84.9
F58	5– 5	89	99	97	88	96	93	96	94	94.0	92	93	84	92	78	79	91	62	86.4
Average		82.1	83.0	83.2	78.2	75.2	78.2	80.0	82.7		66.4	76.0	74.7	68.0	69.0	72.0	82.2	70.6	

TABLE 21
Individual Scores (Average of Three Trials) on the Tracing Path with Right and Left Hands by Children of Six Years

Child	Age	Right hand									Left hand								
		Direction of movement								Average	Direction of movement								Average
	Years Months	1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖		1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	
M48	5– 6	68	87	95	87	77	86	95	88	85.4	83	85	67	77	67	68	87	58	74.0
M50	5– 6	94	93	92	93	98	93	90	95	93.5	89	91	91	90	90	89	97	89	90.8
M52	5– 6	82	96	93	87	87	96	96	96	91.6	84	90	95	79	86	85	91	82	86.5
M53	5– 6	94	93	100	92	88	87	91	86	91.4	93	84	71	84	67	81	93	81	81.8
M54	5– 7	81	67	75	80	77	89	79	88	79.5	70	73	76	88	71	76	76	76	75.8
F60	5– 7	81	80	95	84	91	90	97	91	88.6	73	91	87	90					85.3
F63	5– 9	73	76	77	78	87	73	87	73	78.0	62	71	72	69	67	55	68	80	68.0
F64	5– 9	96	86	91	93	94	94	99	96	93.6	88	85	86	90	87	78	76	86	84.5
M55	5–11	86	83	59	85	91	92	95	87	84.8	63	79	74	77	68	70	75	62	71.0
F68	6– 4	85	77	87	69	77	84	95	78	81.5	62	74	58	58	60	71	90	64	67.1
Average		84.0	83.8	86.4	84.8	86.7	88.4	92.4	87.8		76.7	82.3	77.7	80.2	73.6	74.7	83.6	75.3	

three to six years of age. This correlation is lower than the correlations between age and scores on the right hand (.81 for boys and .82 for girls). This probably means that the tendency for scores to increase with age was not so marked when the left hand was used as when the right hand was used.

PRACTICE EFFECTS AND TRANSFER OF TRAINING

In order to determine whether a child who had had previous experience with the tracing board benefited sufficiently from this experience to raise his score on a second test, the scores on points of first contact of the fifteen children who had had the test a second time were examined. Since the intervals between tests were irregular, the scores on the repeated test were averaged according to the age of the child and these averages checked against the averages on the first test for all children for whom there were scores at these ages. In Table 22 it will be seen that at each age the averages for the children on the repeated test are ahead of these tentative norms. Two explanations for this advantage might be offered: practice effects may have accrued from having had the test before and the group that was given the test a second time may have been a selected group and could be expected to make superior scores. If the group was a superior one, then the scores made on the first test could be expected to be above the average scores for all children at the same ages. That this was not the case may be seen from Table 22, where the scores for these fifteen children on the first test show no significant deviations in a positive direction from the tentative norms. It therefore appears that previous experience with the test tended to increase the scores for these children when the test was repeated. These results are not in accordance with those of Bryan,[3] who, as subject, made 800 trials over a period of three weeks with his tracing board and did not find an observable improvement with practice.

The question as to whether practice in one direction of movement carries over to another direction is difficult to answer from these data, since the matter is complicated by the relative difficulties of the directions. However, if we could assume that all directions were of equal difficulty, and that other conditions were equal, we should expect the scores on the last direction to be higher on account of practice than those for the first direction on a particular

TABLE 22

Average Scores on Point of First Contact on the Tracing Board by Entire Group on First Test and by Repeated Test Group on First and Second Tests

Group and test	Number of children	Right hand									Left hand								
		Direction of movement								Average	Direction of movement								Average
		1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖		1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	
3 years																			
Entire group—1st test	18	6.6	5.3	6.5	4.5	5.0	6.1	5.3	4.1	5.4	4.4	3.6	5.0	4.5	5.3	3.9	4.6	5.2	4.6
Repeated test group—1st test	5	7.8	5.2	7.5	3.6	4.5	4.1	4.7	3.8	5.1	3.4	3.1	4.7	4.7	5.7	4.0	5.8	6.2	4.7
Repeated test group—2d test	2	6.8	7.5	6.6	6.5	5.8	11.8	8.3	11.0	8.0	5.3	9.6	6.1	4.4	4.4	5.3	3.0	6.7	5.6
4 years																			
Entire group—1st test	15	9.7	5.9	7.1	7.8	8.4	6.6	7.4	6.1	7.6	4.4	5.8	4.4	4.5	7.0	3.7	4.9	4.5	4.9
Repeated test group—1st test	6	11.5	6.8	6.2	9.9	10.3	5.6	7.3	6.6	8.0	2.7	6.7	3.5	4.3	4.9	2.9	3.9	3.6	4.0
Repeated test group—2d test	8	7.6	7.6	5.0	9.7	6.9	11.7	9.0	5.7	7.9	6.9	4.1	4.8	7.1	10.5	6.7	4.5	6.6	6.4
5 years																			
Entire group—1st test	10	10.9	11.2	10.4	9.2	9.4	11.2	10.4	10.7	10.4	6.1	4.7	6.5	5.5	5.4	5.3	7.3	5.4	5.8
Repeated test group—1st test	4	13.8	10.7	10.8	8.8	12.0	11.0	6.7	11.0	10.6	5.4	5.4	3.9	3.8	2.3	2.3	7.7	3.0	4.2
Repeated test group—2d test	5	11.7	11.1	13.2	11.0	12.8	14.5	12.9	12.2	12.4	5.8	5.4	6.6	7.5	11.6	9.8	5.7	5.6	7.2

day, and the scores on the second day could also be expected to be higher than those on the first day. Neither of these results is found. The last direction on a particular day does not give the highest score, and the second day's scores are not higher than the first day's scores. How much experience with the right hand on a particular

TABLE 23

Average Scores on the Tracing Path by Entire Group on First Test and by Repeated Test Group on First, Second, and Third Tests

Group and test	Number of children	Direction of movement								Average
		1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	
3 years										
Entire group—1st test	33	52.4	47.6	45.8	47.9	53.2	51.0	51.4	51.0	50.0
Repeated test group—1st test	16	51.3	44.8	47.4	51.6	52.0	50.8	50.0	49.0	49.6
Repeated test group—2d test	5	64.0	56.6	58.8	59.4	61.0	51.0	55.0	56.0	57.7
4 years										
Entire group—1st test	33	71.4	61.5	69.1	59.9	69.8	68.1	63.1	67.0	66.2
Repeated test group—1st test	15	71.0	65.9	73.6	63.8	66.8	71.8	65.4	70.0	68.3
Repeated test group—2d test	16	74.7	70.8	71.7	68.1	83.0	73.4	75.2	80.3	74.6
5 years										
Entire group—1st test	39	88.0	83.7	82.8	80.4	84.6	84.1	83.9	84.0	83.9
Repeated test group—1st test	15	83.1	78.3	77.7	75.0	81.2	80.6	78.1	79.0	79.1
Repeated test group—2d test	21	89.2	82.5	81.1	81.7	91.5	91.0	88.5	88.8	86.8
Repeated test group—3d test	7	90.7	86.1	81.8	81.2	92.3	90.3	83.3	85.8	86.4
6 years										
Entire group—1st test	20	89.8	88.2	89.4	86.9	90.1	91.4	92.3	90.8	89.9
Repeated test group—1st test	3	77.0	80.3	83.7	82.7	77.0	86.0	95.0	88.0	83.7
Repeated test group—2d test	7	93.0	90.7	91.8	90.8	98.6	94.4	96.0	94.8	93.8
Repeated test group—3d test	3	97.7	96.0	94.7	92.0	98.0	95.3	91.3	93.7	94.8

direction may transfer to the left hand on that same direction is not apparent from these data.

Forty-nine children were given the tracing path test twice; ten of these were given the test a third time. Table 23 gives the average scores by ages for these children on these repeated tests, with their scores on their first tests compared with the average scores of all the children on the first tests used as tentative norms. It will be seen that the averages for the second test group are ahead of the norms for practically every direction of movement at every age. The combined average for all directions is higher at each age for the second test group than for the norm group. That this advantage was not due to the selection of the group for the repeated tests may be seen by comparing the scores of this group on their first test with the tentative norms. Their averages for the first test fall slightly below the norm averages for their ages. It would seem then that the children made higher scores on their second test because of previous experience with the test.

Data that are at hand for ten children who were given the test a third time seem to indicate that while the advantage from the second test was maintained, there was no appreciable gain from the second to the third test. However, the number of third tests is too small to consider the findings more than an indication of tendency.

That the scores on the tracing path do not show an increase that can be attributed to order of testing of the directions is evidenced by the rankings for the various age groups. Although the actual rankings vary at the various ages, the general tendencies are similar. At no age does the eighth direction (↖) tested rank first in score. The fourth direction tested (←), which was the last of the series on the first day, ranks lower than any other direction, and the first direction (↓) ranks highest of all eight. If there was transfer of training from one movement to the next, it is not evident from these data.

RELATIVE DIFFICULTIES OF THE EIGHT DIRECTIONS

Tracing Board Experiment

No one direction of movement on the tracing board stands out as consistently easier or more difficult than the others for all age groups, when actual differences alone are considered, irrespective of the significance of these differences. The rankings for order of difficulty within an age group change according to whether the

score used is the point of first contact or the percentage within the path. When the formula for determining the standard error of differences between the means when correlated measures are involved[8] is applied, and a correlation of .40 is assumed when the actual correlations have not been computed, it is found that there is no combination of two directions in which there are significant differences between the means in at least three of the four age groups by both methods of scoring (point of first contact and percentage within the path), although there are occasional significant differences within an age group.

The correlations between the points of first contact on different directions of movement were worked out for five combinations of directions for the fifty-four children:

				r	P.E.
Direction 1	(↓)	with 3	(↑)	.16	± .09
Direction 2	(→)	with 4	(←)	.45	± .08
Direction 5	(↙)	with 7	(↗)	.70	± .06
Direction 6	(↘)	with 8	(↖)	.40	± .09
Direction 2	(→)	with 7	(↗)	.46	± .09

All of these correlations are significant, except for the combination of directions 1 (↓) and 3 (↑), indicating that a child who makes a high score on one of these directions tends to make a high score on another of these directions.

Bolton[12] found that with children of eight years and older movements toward the body, as tested by the tracing board, were more steady than movements away from the body. Right and left hands were tested in four directions: directions 1 (↓), 2 (→), 3 (↑), and 4 (←). Thompson[99] also found that adults made better scores on movements toward the body than on movements away from the body. Town[103] tested five and six-year-old children on direction 2 (→) with the right hand and on direction 4 (←) with the left hand, but found it necessary to discard the left hand scores because of their large probable errors.

The present results do not show significant differences between the scores made on movements toward and away from the body.

Tracing Path Experiment

If the rankings of the means in the tracing path experiment for

8. $\sigma_{\text{difference}} = \sqrt{\sigma^2_1 + \sigma^2_2 - 2r_{12}\sigma_1\sigma_2}$
Kelley, T. L. *Statistical Method.* New York: Macmillan, 1923. Pp. 390 (p. 182).

the eight directions for the half year groups are considered irrespective of the significance of the differences of the means, it is found that direction 1 (↓) ranks first or second in five of the seven age groups and that direction 4 (←) ranks eighth in three of the groups and never higher than fifth. Direction 2 (→) is next to 4 (←) in rank, and 3 (↑) comes next, while the four angle movements rank between 1 (↓) and 3 (↑). Judging from the rankings alone, directions 4 (←) and 2 (→) were the most difficult movements and direction 1 (↓) the easiest. These rankings can only give indications of difficulties, however, since the significance of the differences of the means should be taken into consideration. The significance of these differences will be discussed later in connection with the correlations of scores.

It seemed probable that the averages might cover up individual differences and that a certain direction or combination of directions might be easy for one type of child and difficult for another type. Attempts to classify the individuals into types on the basis of combinations of the ranks of the directions on the tracing path were, however, unsuccessful.

Accuracy and Time of Each Trial.—The scores thus far reported for the children have been the averages of three trials in each direction of movement. In order to determine whether there was the same degree of accuracy for each of these trials, the average score of all children on the tracing path was computed separately for each trial. Since the child was allowed to choose his own rate of speed for the experiment, it seemed probable that there might be some relationship between the accuracy of a trial and the time that the child spent on it. The average number of seconds spent by all children on each trial was therefore also computed. Table 24 gives these average scores and average times for each direction of movement.

While the differences in scores are small between the first, second, and third trials, it will be noted that the first trial was the most accurate of the three for each direction of movement. Longer times were also spent on the first trial than on the other two trials for each direction except direction 6 (↘). There was a gradual quickening in time from one direction to the next within a day's experiment, so that the average time spent on the fourth direction tested on each day was considerably less than the time spent on

TABLE 24
Average Scores and Average Times on Each of the Three Trials on the Tracing Path by Entire Group

Trial	Direction of movement															
	1 ↓		2 →		3 ↑		4 ←		5 ↙		6 ↘		7 ↗		8 ↖	
	Score	Time	Score	Time	Score	Time	Score	Time	Score	Time	Score	Time	Score	Time	Score	Time
First	75.5	22.0	73.8	16.2	73.2	13.1	71.6	10.8	79.2	18.1	78.7	12.8	74.0	13.3	78.0	11.1
Second	72.9	17.0	66.7	14.3	70.4	11.7	68.2	10.1	73.7	16.1	73.5	14.0	71.2	12.5	72.2	9.4
Third	74.5	15.9	69.8	12.9	69.8	10.4	66.7	10.1	72.2	13.3	70.6	12.1	73.1	12.9	70.3	9.3

the first direction that day. This quickening in time might be interpreted as meaning that the directions became progressively easier, that the child was benefiting from each previous trial and "getting into the swing" of the test, that he was becoming more confident, or that he was losing interest and becoming careless. Introspections would have helped here, had it been possible to get them from preschool children. It was possible to test some adults to learn whether the same tendencies in time operated and to get their introspections. Six adults were tested on the first four directions. Their average times in seconds were as follows:

	Direction			
	1 ↓	2 →	3 ↑	4 ←
First trial	18.2	7.5	8.2	7.2
Second trial	11.5	6.7	8.0	6.3
Third trial	9.8	6.7	8.2	6.0

Their times showed the same tendency as those of the children, that

TABLE 25

Correlations between Times on First, Second, and Third Trials for the Eight Directions on the Tracing Path

Direction of movement	Direction of movement						
	1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗
3 to 7 years (88 children, 264 correlated pairs)							
2 →	.66						
3 ↑	.64	.64					
4 ←	.62	.70	.63				
5 ↙	.45	.31	.22	.37			
6 ↘	.36	.37	.32	.25	.42		
7 ↗	.18	.25	.21	.34	.26	.31	
8 ↖	.36	.35	.30	.40	.45	.40	.37
3 years (24 children, 72 correlated pairs)							
2 →	.72						
3 ↑	.71	.68					
4 ←	.66	.64	.63				
5 ↙	.27	.09	−.01	.07			
6 ↘	.39	.37	.23	.21	.54		
7 ↗	.10	.08	.15	.21	.28	.41	
8 ↖	.30	.02	.01	.24	.30	.30	.20

4 years (18 children, 54 correlated pairs)							
2 →	.57						
3 ↑	.62	.51					
4 ←	.32	.41	.64				
5 ↙	.21	.03	.07	−.01			
6 ↘	.29	.39	.21	.17	.21		
7 ↗	−.01	−.08	−.01	.07	.12	.18	
8 ↖	.08	.01	.11	.15	.28	.06	.04
5 years (24 children, 72 correlated pairs)							
2 →	.39						
3 ↑	.29	.22					
4 ←	.31	.40	.26				
5 ↙	.50	.17	.21	.28			
6 ↘	.32	.11	.35	.11	.46		
7 ↗	.14	.16	.25	.27	.29	.15	
8 ↖	.30	.23	.21	.16	.44	.43	.38
6 years (16 children, 48 correlated pairs)							
2 →	.87						
3 ↑	.79	.84					
4 ←	.86	.92	.82				
5 ↙	.58	.56	.33	.59			
6 ↘	.44	.37	.34	.34	.50		
7 ↗	.15	.29	.15	.29	.19	.26	
8 ↖	.47	.53	.40	.48	.58	.54	.24

is, a general decrease as the test progressed, the fourth direction (←) taking less time than any other, in spite of the fact that three of the six adults considered the fourth direction the most difficult. Two considered direction 3 (↑) the most difficult and the other person was uncertain. They were conscious that their speed was increasing, but attributed it mainly to motor habituation. One tendency in the children's time that was not evident for the adults was that for the children the first trial in a new direction took a longer time than the third trial of the preceding direction. Evidently for the child a new direction presented more elements of a new situation than for an adult. The adults made practically perfect score throughout.

In order to determine how much relationship there actually was between the time and the accuracy of a particular trial, correlations between the times and between the scores on separate trials on the eight directions and correlations between the scores and times on separate trials were worked out.

Correlations between Times and between Scores on Separate Trials.—The correlations between the times for the trials on the different directions on the tracing path are given in Table 25. There were eighty-eight children for whom scores and times were available for each of the three trials on all eight directions of movement, making a total of 264 correlated pairs. When the entire group was used, the correlations between times on the different directions were significant in all cases, but varied in size from .18 between directions 1 and 7 to .70 between directions 2 and 4. The correla-

TABLE 26

Correlations between Scores on First, Second, and Third Trials for the Eight Directions on the Tracing Path

Direction of movement	Direction of movement						
	1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗
3 to 7 years (88 children, 264 correlated pairs)							
2 →	.67						
3 ↑	.67	.74					
4 ←	.66	.76	.71				
5 ↙	.63	.59	.62	.63			
6 ↘	.58	.63	.62	.61	.66		
7 ↗	.60	.69	.65	.66	.67	.59	
8 ↖	.61	.61	.65	.66	.69	.65	.70
3 years (24 children, 72 correlated pairs)							
2 →	.17						
3 ↑	.27	.29					
4 ←	.27	.41	.24				
5 ↙	.20	.08	.32	.17			
6 ↘	.07	.35	.24	.16	.29		
7 ↗	.08	.33	.17	.17	.26	.06	
8 ↖	.12	−.01	.20	.21	.41	.20	.24
4 years (18 children, 54 correlated pairs)							
2 →	.50						
3 ↑	.46	.64					
4 ←	.39	.61	.55				
5 ↙	.24	.33	.22	.42			
6 ↘	.17	.26	.22	.33	.35		
7 ↗	.11	.32	.40	.40	.38	.29	
8 ↖	.21	.34	.22	.32	.44	.35	.52

5 years (24 children, 72 correlated pairs)							
2 →	.28						
3 ↑	.16	.40					
4 ←	.27	.44	.50				
5 ↙	.28	.17	.19	.13			
6 ↘	.21	.15	.17	.17	.39		
7 ↗	.42	.44	.25	.35	.44	.26	
8 ↖	.28	.24	.41	.42	.38	.48	.44
6 years (16 children, 48 correlated pairs)							
2 →	.01						
3 ↑	.12	.31					
4 ←	.17	.18	.28				
5 ↙	.42	−.30	.03	.24			
6 ↘	.51	−.06	.34	.23	.37		
7 ↗	−.07	−.07	.30	.28	−.04	.13	
8 ↖	.25	.18	.40	.45	−.01	.36	.24

tions between the first four directions were much higher than the other correlations. The average for a specific direction with all others ranged from .35 to .46. There was thus a definite tendency for the children to be consistent in the amounts of time that they spent on two directions. They were much more consistent for directions 1, 2, 3, and 4 than for any other combinations. This does not mean that they spent the same amounts of time on the different directions, but that the trend for time taken was in the same direction for different children.

Correlations between times on the tracing path for the separate age groups were also computed. At three years, seventy-two pairs were included in the calculations, at four years, fifty-four pairs, at five years, seventy-two pairs, and at six years, forty-eight pairs. At seven years there were eighteen pairs for which correlations were not computed because of the small number of children. A correlation of .21 or above is significant for the three and five-year groups, and a correlation of .27 or above is significant for the four and six-year groups.

The correlations between scores on the separate trials that are given in Table 26 are all significant and high for the entire group, indicating that a child making a high score on one direction is likely to make a high score on another direction. The same group

TABLE 27

Means and Standard Deviations for Correlations between Times and Correlations between Scores on Separate Trials on the Tracing Path

	Times								Scores							
	Direction of movement								Direction of movement							
	1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖	1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖
3 to 7 years																
Means	17.8	14.3	11.5	10.3	15.9	12.5	12.8	9.8	73.4	69.2	70.6	68.0	74.4	73.3	72.1	72.8
S.D.	14.6	11.5	8.5	6.9	10.4	6.8	7.1	4.5	23.4	25.1	24.6	24.1	21.8	23.1	22.9	22.4
S.D. M	.9	.7	.5	.4	.6	.4	.4	.3	1.4	1.5	1.5	1.5	1.3	1.4	1.4	1.4
3 years																
Means	9.6	8.2	7.3	6.5	12.2	10.6	10.0	7.4	50.2	45.6	44.7	46.0	54.0	51.2	51.4	51.8
S.D.	6.7	7.9	4.9	3.9	8.0	6.0	5.6	3.4	19.8	19.2	18.9	19.5	16.3	20.7	19.1	20.3
S.D. M	.8	.9	.6	.5	.9	.7	.7	.4	2.4	2.3	2.2	2.3	1.9	2.5	2.3	2.4
4 years																
Means	20.6	16.0	13.4	10.0	16.7	14.3	12.8	10.1	67.9	60.3	67.3	58.0	69.6	68.1	63.1	66.7
S.D.	14.8	12.1	11.6	4.8	9.8	8.4	6.3	4.1	18.4	24.2	22.2	22.2	19.0	20.4	18.8	18.1
S.D. M	2.0	1.7	1.6	.7	1.3	1.2	.9	.7	2.5	3.3	3.0	3.0	2.6	2.8	2.6	2.5
5 years																
Means	20.0	15.1	11.4	11.4	17.6	12.0	12.1	10.0	87.1	84.8	83.0	81.2	85.5	84.1	84.0	84.1
S.D.	12.4	6.6	5.9	5.6	10.9	6.0	6.1	3.7	14.1	12.9	13.0	13.1	14.2	13.9	13.0	10.7
S.D. M	1.4	.8	.7	.7	1.3	.7	.7	.4	1.6	1.5	1.5	1.5	1.6	1.6	1.5	1.2
6 years																
Means	20.2	18.7	14.7	14.1	18.0	13.7	18.3	12.5	89.3	89.0	89.1	86.4	90.0	91.2	92.4	90.5
S.D.	19.9	15.9	10.1	10.9	12.9	6.1	8.5	4.7	11.8	8.1	13.1	9.8	11.8	8.4	8.7	9.9
S.D. M	2.9	2.3	1.5	1.6	1.9	.9	1.2	.7	1.7	1.2	1.9	1.4	1.7	1.2	1.3	1.4

of children was used as for the correlations between times. When the age range is narrowed to one year, the correlations between scores on the different directions drop considerably.

The means, standard deviations of the distributions, and standard errors of the means for these correlations between times and between scores are given in Table 27. It will be noted that the means for times decrease from the first to the last direction tested on a day and that the standard deviations for times decrease in the same way. The children grow more alike in the times they spend as

TABLE 28
Correlations between Scores and Times on Separate Trials for the Eight Directions on the Tracing Path

Age, Years	Number of children	Number of correlated pairs	Direction of movement							
			1 ↓	2 →	3 ↑	4 ←	5 ↙	6 ↘	7 ↗	8 ↖
3 to 7	88	264	.39	.51	.46	.49	.37	.38	.48	.55
3	24	72	.23	.39	.49	.50	.15	.36	.48	.48
4	18	54	.40	.65	.47	.64	.47	.54	.41	.54
5	24	72	.28	.28	.13	.21	.41	.35	.37	.44
6	16	48	.34	.67	.47	.46	.27	.24	.50	.47

they progress from direction to direction. Neither the means nor standard deviations of the scores follow this trend of growing less from direction to direction. The children do not grow more alike in scores as they progress from direction to direction.

Correlations between Scores and Times on Separate Trials.—The correlations between times and scores for a specific direction (Table 28) are all significant except for direction 5 at three years, for directions 3 and 4 at five years, and directions 5 and 6 at six years. Directions 1, 2, 7, and 8 are the only directions for which the correlations between times and scores are significant for every age group.

Significant Differences in Means.—When the formula for determining the standard error of the means when correlated measures are involved is applied to the means of the times and of the scores, it is found that there is only one combination, directions 4 and 5, in which there are significant differences in the means for both times and scores in at least three of the four age groups. There are two combinations, directions 3 and 6 and directions 6 and 7, in

which no significant differences are found in either time or score in at least three age groups. There is only one combination, directions 4 and 8, in which significant differences are found between the scores but not between the times, and there are nine combinations in which significant differences are found in times but not in scores for at least three age groups. These nine combinations are:

Directions 1 and 3	Directions 2 and 4
Directions 1 and 6	Directions 5 and 6
Directions 1 and 8	Directions 5 and 8
Directions 2 and 3	Directions 6 and 8

Directions 7 and 8

In the combination of directions 4 and 5, the mean time and mean score are lower for direction 4 than for 5, but the correlation between time and score for each direction is not high enough to indicate that time is a primary factor in the score. The correlations for scores and for times for the age groups indicate that the children are not consistent in the times that they take on the two directions, nor on the scores they make. Since, as has been pointed out previously, the time taken decreases from movement to movement, the differences in time between directions 4 and 5 may be due to sequence in the series. Direction 4 is the last for a day and direction 5 the first for a day. When all the combinations of first and last movements in a series are compared it is found that directions 1 and 4 differ in both scores and times at four and five years and in times but not in scores at three and six years; that directions 1 and 8 and directions 5 and 8 differ in times but not in scores at all ages; and that directions 4 and 5 differ in both scores and times at all ages. When the two first and two last movements are compared it is found that directions 1 and 5 differ in times at three years and five years, but show no difference at four years and six years, and that directions 4 and 8 differ in times only at five years and in scores only at three, four, and six years. On the basis of these facts, it can be concluded that the significant difference in scores between directions 4 and 5 is not entirely due to sequence in the series, or to time spent, but may be due to the greater difficulty of direction 4.

For the directions 4 and 8, in which significant differences were found in scores but not in times, the sequence within a day's series is the same, that is, both are last movements. The correlations between scores are probably all significant, but the correlations be-

tween times are not significant. Since the mean score for direction 4 is lower than that for 8, direction 4 is probably more difficult than 8.

For the three directions in the combinations in which there are no significant differences in the means either for scores or for times, directions 3 and 6 and directions 6 and 7, the sequence in the series is practically the same. Some of the correlations between scores and between times are significant and some are not. For this group of directions there is probably no difference in difficulty.

In every combination except directions 2 and 3 of the nine combinations in which there are significant differences in times but not in scores a first or last placement is involved. In every case the earlier of the two movements shows the longer time, indicating that the placement of the movement is affecting the time. Combinations of directions 2 and 3, 5 and 6, and 7 and 8 are the only cases in which two movements that are next to each other show significant differences in time. For directions 2 and 3 the correlations are significant and high throughout for scores, indicating that a child who makes a high score on direction 2 also makes a high score on 3. The correlations between times are also significant and high, indicating that a child who spends a long time on direction 2 also spends a long time on 3. Since this is the only combination of middle-placed movements in which there is a significant difference in times, the difference in times is probably due to a real difficulty in direction 2 as compared with 3.

Combinations of directions 1 and 3, 1 and 6, and 1 and 8 show differences in times, but not in scores. Since there is a positive correlation for the times and a lack of correlation for the scores, it is fairly certain that the differences in times are due to position in the series. The same is probably true of directions 5 and 8, although there is a little more correlation between the scores here.

Direction 2 takes a significantly longer time than 4. The correlations are very high for times and high for scores, except at six years, but since another direction intervenes between directions 2 and 4, the difference in times is probably due to sequence in the series.

Directions 6 and 8 are in the same relative sequence as 2 and 4. The correlations except at age three for scores and at age four for times are all significant for the combination of directions 6 and 8,

and the difference in times is probably due to placement here also.

Directions 7 and 8 are adjacent in sequence and do not show differences in scores, but do show differences in times. The correlations for scores may be significant, but the correlations for times probably are not significant. This is the only combination in which the correlations for times are not significant. Since the children are not consistent in the times on directions 7 and 8, and the mean scores show no differences, it can not be stated that direction 7 is more difficult than 8.

There is a significant difference in times but not in scores for directions 5 and 6. The correlations for scores are significant and for times also significant and high. Since these two directions are adjacent, the greater time on direction 5 than on 6 is probably due to greater difficulty with 5 than with 6.

In summing up the conclusions, then, it is found that:

Direction 4 (←) is probably more difficult than 5 (↙) and 8 (↖)
No difference is found between directions 2 (→) and 4 (←)
Direction 2 (→) is more difficult than 3 (↑)
Direction 5 (↙) is more difficult than 6 (↘)
No difference is found between directions 3 (↑) and 6 (↘) and between 6 (↘) and 7 (↗)
No difference is found between directions 1 (↓) and 3 (↑), 1 (↓) and 6 (↘), and 1 (↓) and 8 (↖)
No difference is found between directions 6 (↘) and 8 (↖)
Direction 7 (↗) may be more difficult than 8 (↖)

Of the combination of directions 2 and 5 at three years, direction 2 takes a shorter time than 5 and gains a lower score; at four years there is no difference for time, but direction 5 gains a higher score; at five years direction 2 takes a longer time than 5, but there is no difference in the scores; and at six years there is no difference either in scores or times. These findings indicate that direction 2 is more difficult than 5. The final conclusion as to relative difficulties, then, is:

Directions 2 (→) and 4 (←) are the most difficult
Direction 5 (↙) is third in difficulty
Directions 3 (↑), 6 (↘), 7 (↗), and 1 (↓) are relatively easy
Direction 8 (↖) is probably the easiest of all directions

There is a possibility that direction 1 (↓) may be the easiest of all eight directions, but due to the fact that it occupies the position

of the very first direction tested, when the child is facing an entirely new situation, it is impossible to determine definitely just where direction 1 should stand.

TABLE 29
Correlations between Scores (Average of Three Trials) on the Different Directions on the Tracing Path

Age, Years	Number of children	Direction of movement									
		1 ↓ and 3 ↑		2 → and 4 ←		5 ↙ and 7 ↗		6 ↘ and 8 ↖		2 → and 7 ↗	
		r	P.E.	r	P.E.	r	P.E.	r	P.E.	r	P.E.
3 to 7	93	.84	± .02	.89	± .01	.84	± .02	.85	± .02	.80	± .03
3	25	.41	± .11	.51	± .10	.39	± .11	.39	± .11	.32	± .12
4	18	.66	± .09	.79	± .06	.63	± .10	.59	± .10	.46	± .13
5	26	.46	± .10	.71	± .06	.74	± .06	.66	± .07	.59	± .08
6	17	.38	± .14	.77	± .07	.35	± .14	.90	± .03	.41	± .13

Correlations between Scores on Three Trials.—When the average of the three trials which make up the score in the other sections of this study is used instead of scores on separate trials, the correlations between the scores on the different directions are raised in every instance, as will be seen in Table 29, in which five combinations are reported for each age group. The correlations here are all significant and high and indicate that when a child's scores are based on the average of three trials they are more likely to be similar for two directions than when the scores are based on separate trials.

Deviations from Straight Line.—Although when the children were given the tracing path test they were instructed merely to stay within the path, there was a tendency for the older child to make a straighter line than that of the younger child. How much more nearly straight this line was could be measured by our method of scoring. The difference was found between the total length of the line made and a hypothetical straight line from its start to finish, and this difference divided by the length of the straight line (in most cases 25 cm.) in order to obtain the percentage of deviation from the straight line. Table 30 gives the average deviations and standard deviations from these averages for each half year group.

There was a definite tendency for the deviations to become less as age increased, that is, for the lines made to approximate more nearly straight lines, as will be seen from the combined averages for the eight directions. There was also a tendency for direction

TABLE 30

Average Percentage of Deviation from a Straight Line on the Tracing Path by Children from Three to Six Years of Age

Age, Years	Number of children	Direction of movement														Average
		1 ↓		2 →		3 ↑		4 ←		5 ↙		6 ↗		7 ↗		8 ↖		
		Dev.	S.D.	Dev.	S.D.	Dev.	S.D.	Dev.	S.D.	Dev.	S.D.	Dev.	S.D.	Dev.	S.D.	Dev.	S.D.	
3	18	3.7	1.8	4.1	4.6	3.6	2.8	4.6	4.0	5.4	3.6	5.8	5.3	6.7	7.4	3.3	2.7	4.7
3½	28	4.0	2.9	4.2	2.7	4.8	5.8	4.4	4.0	3.8	2.5	3.2	3.1	4.9	6.0	3.4	2.5	4.1
4	12	4.9	3.8	5.0	4.2	4.0	3.9	5.1	4.6	2.4	.7	1.4	.5	2.3	.6	1.4	.3	3.3
4½	15	4.2	3.2	3.8	1.7	2.5	2.8	2.3	1.3	3.5	2.9	2.2	1.6	2.5	1.3	1.7	1.3	2.8
5	17	5.2	6.1	3.4	3.9	1.9	1.6	2.9	2.9	3.0	1.4	1.8	1.8	1.2	.9	1.2	.5	2.6
5½	23	3.4	3.5	2.5	2.9	2.0	2.5	3.1	2.4	3.5	3.5	1.9	1.7	2.7	2.7	1.6	1.3	2.6
6	9	1.8	2.4	2.0	1.1	1.5	.9	2.5	1.5	1.5	.7	2.8	4.0	1.8	.8	1.8	1.2	2.0

8 (↖) to show less deviation than the other directions, with its opposite direction 6 (↘) and direction 3 (↑) ranking next in order, while 1 (↓), 2 (→), and 4 (←) tended to show the greatest deviation.

RELATION BETWEEN CO-ORDINATIONS IN EXPERIMENTS WITH TRACING BOARD AND TRACING PATH

Correlations between scores on the separate directions on the tracing path and point of first contact on the tracing board were worked out in order to determine whether a child tended to make similar scores on the same direction for the two tests. The correlations for the entire group, ages three to six, were as follows:

	r	P.E.
Direction 1 (↓)	.25	±.09
Direction 2 (→)	.53	±.07
Direction 3 (↑)	.23	±.09
Direction 4 (←)	.48	±.07
Direction 5 (↙)	.40	±.09
Direction 6 (↘)	.54	±.08
Direction 7 (↗)	.52	±.08
Direction 8 (↖)	.44	±.09
Combined	.69	±.05

While there was a positive relationship between scores on the same direction for the two tests, the correlations were considerably lower than the correlations between the directions on the tracing path (.80 to .86), but were about the same as the correlations between the directions on the tracing board. These correlations between the two tests would probably have been reduced if the age range had been narrower. When all eight directions were combined, the correlation was raised to .69 ± .05, but when age was held constant by the method of partial correlation, the correlation dropped to .29 ± .09, which, while positive, was only slightly greater than three times the probable error. The correlation between the combined scores for the eight directions on the tracing path and the combined scores for the eight directions on percentage within the path for the tracing board was .75 ± .04, when the entire group of children was used. When age was held constant, the correlation became .47 ± .07. This correlation is considerably higher than the .29 obtained when point of first contact was used as the score, and indicates that when percentage within the path was used children who scored high on the tracing

path test also scored high on the tracing board test. From these correlations it seems, therefore, that there was a very slight relationship between the point of first contact on the tracing board and the tracing path scores, considering that they were intended to measure practically the same function, but that scoring by the method of percentage within the path brought the tracing board results into closer agreement with the tracing path results.

CHAPTER V

PSYCHOPHYSIOLOGICAL ELEMENTS OF MOVEMENTS IN EXPERIMENT WITH TRACING PATH

Examination of the lines made by the children in attempting to keep within the path in the tracing path experiment on motor coördination shows that there were marked differences in the products at the various age levels. The younger child who succeeded with the test kept within the path but a relatively short time, made a sweeping curve out of the path, and in attempting to get back in the path swung as much to the other side, so that his line crossed and recrossed the path in a rhythmical fashion. The still younger child who failed to understand the task made a quick slashing movement down the sheet of paper outside the path and did not attempt to swing into the path. The line that he produced was straighter than that of the child who made a low score. Figures 4, 5, and 6 are photographs of the records of six children for directions 2 ($\rightarrow$), 3 ($\uparrow$), and 5 ($\swarrow$) respectively, selected to show the general trends of lines and how the same type of line was produced by a given child throughout the various directions of movement.

The record at the extreme left in each figure is that of F4, whose line sweeps back and forth across the path. This child was two years, eleven months old. The next record is that of a child three years, one month old who made a slightly higher score because she was able to change the direction of movement more abruptly. The remaining records show progressively more abrupt changes in the direction of movement and a consequent ironing out of the lines to the line of M59, who kept almost entirely within the path although he fluctuated back and forth. This boy was six years, nine months of age and his scores were 95, 100, and 100 respectively for these three directions.

What are the muscular factors that operate to produce these differences in performance at the various age levels? Are there differences in muscular adjustments that affect the scores, and, if so, are these differences intrinsic and necessary or are they due to psychological control? The question of differences in muscular

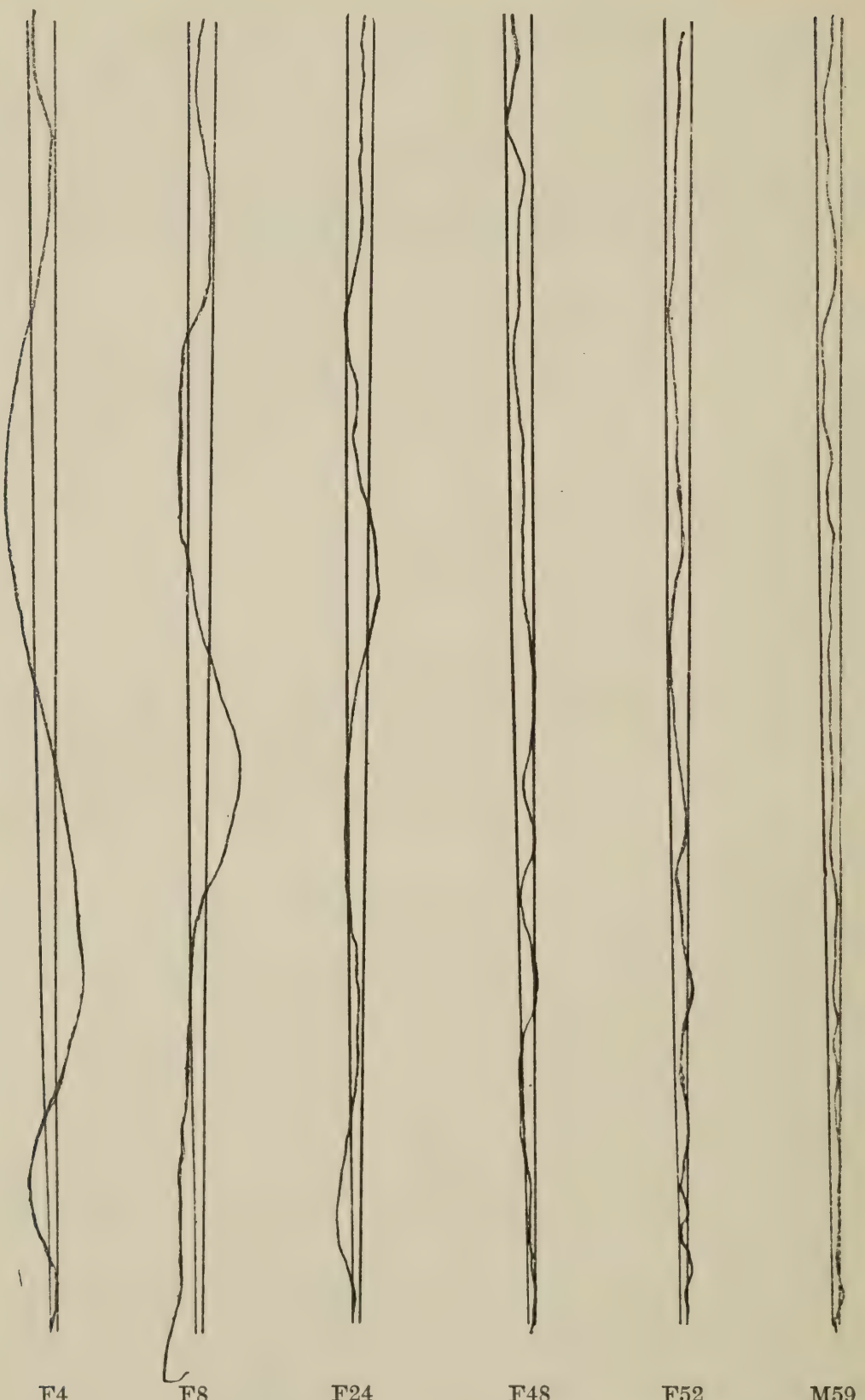

Fig. 4. Lines of six children on direction 2 (→)

Child	F4	F8	F24	F48	F52	M59
Age, years and months	2-10	3-1	3-8	5-0	5-3	6-9
Score	35	38	66	83	90	95
Time, seconds	6	4	8	14	11	13

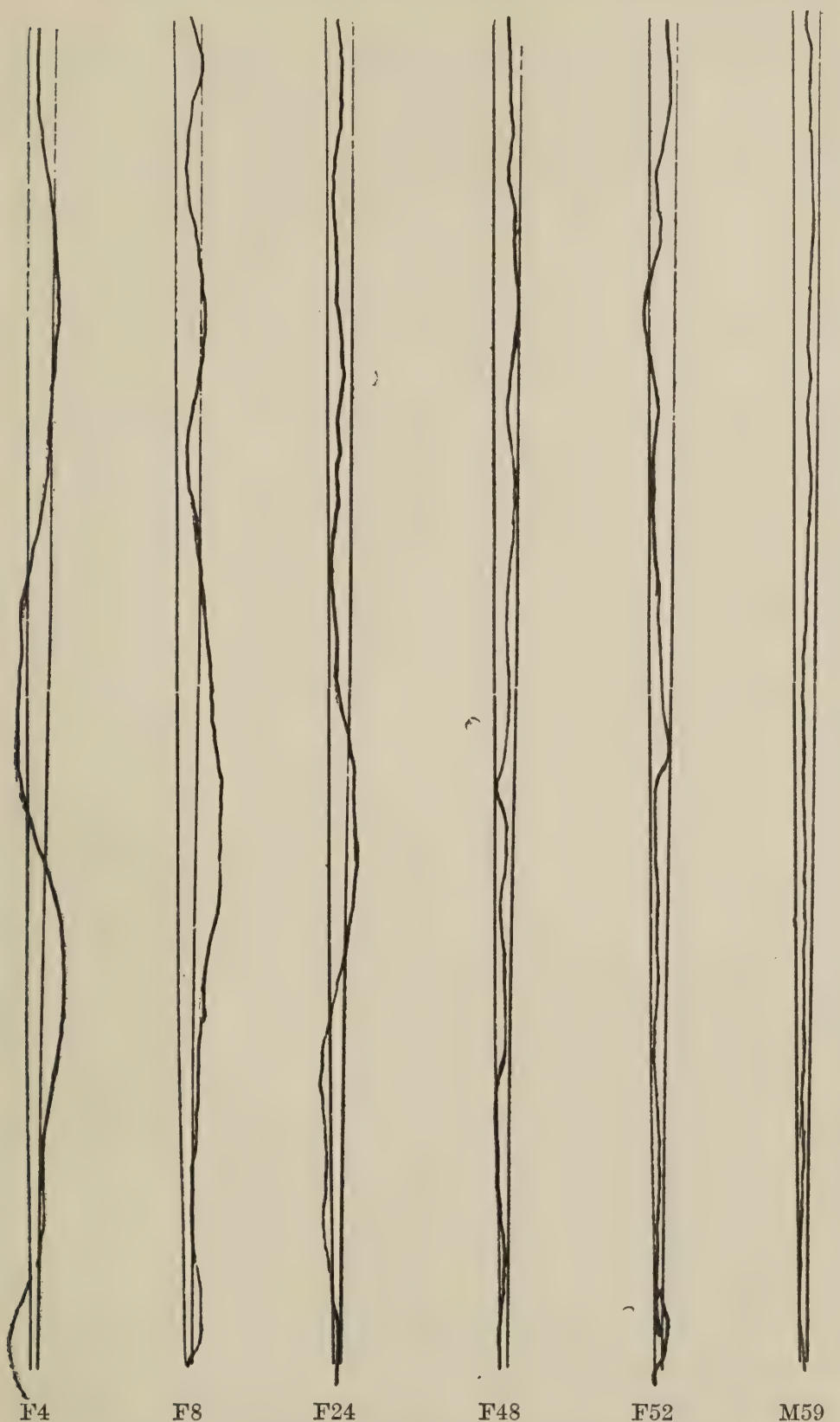

Fig. 5. Lines of six children on direction 3 (↑)

Child	F4	F8	F24	F48	F52	M59
Age, years and months	2-10	3-1	3-8	5-0	5-3	6-9
Score	34	41	64	88	90	100
Time, seconds	6	6	9	10	16	10

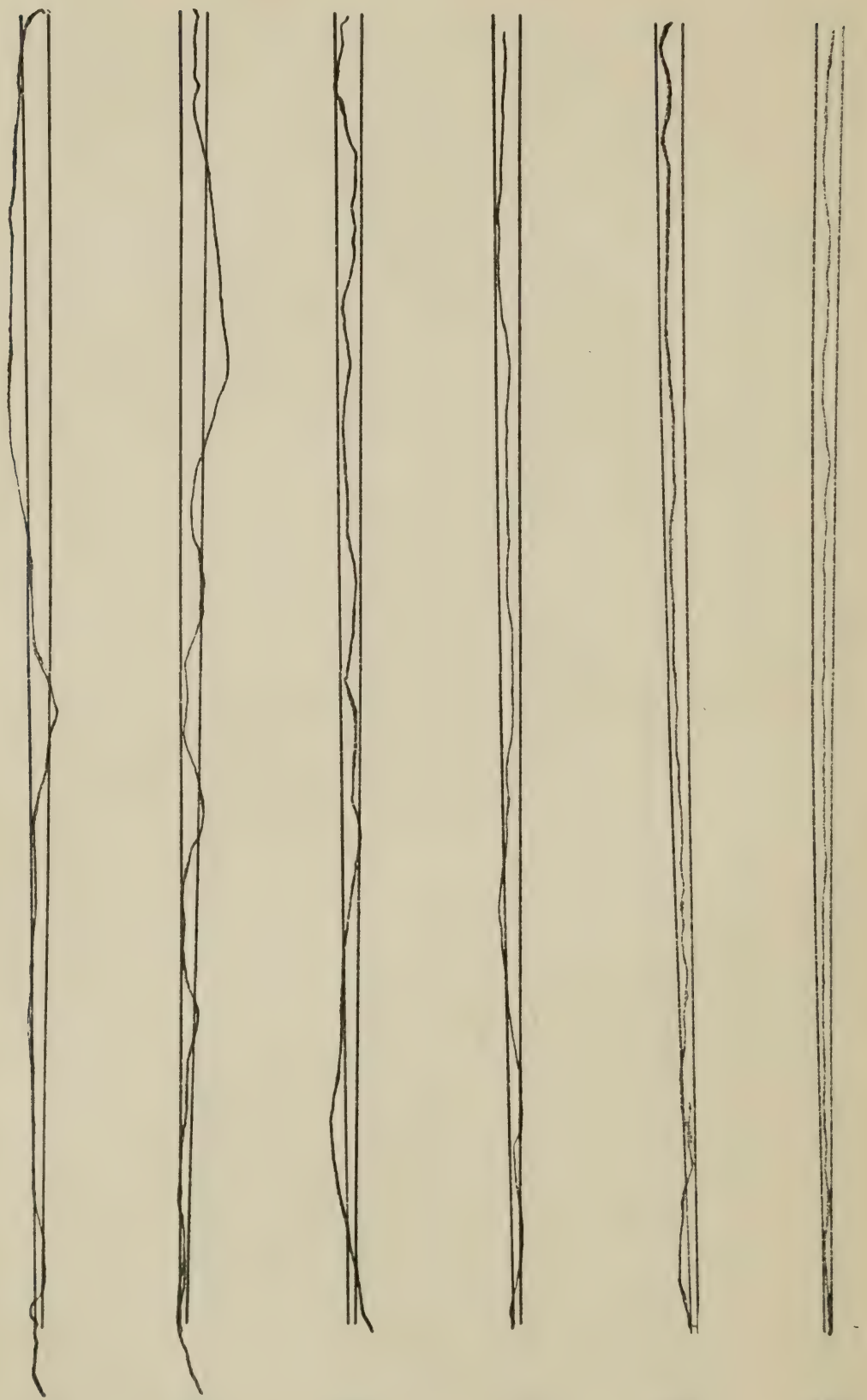

Fig. 6. Lines of six children on direction 5 (↙)

Child	F4	F8	F24	F48	F52	M59
Age, years and months	2-11	3-2	3-8	5-1	5-3	6-9
Score	44	60	73	81	86	100
Time, seconds	9	13	12	18	16	13

adjustments may be answered in part by an analysis of the mechanics of the movements that the children make while performing the task. Some insight into the psychological factors of control may be gained by changing the psychological conditions of the task but keeping the muscular requirements as constant as possible.

MECHANICS OF MOVEMENTS

Analysis was made of the movements in terms of physiological adjustments, flexion, extension, abduction, adduction, pronation, supination, and torsion. The analysis was made by observation of the children as they actually performed the test according to the usual procedure. For about half of the records obtained, two observers[9] noted the active movements involved in the performance; one recorded the movements of the trunk, shoulder, and elbow, while the other recorded the movements of the forearm, wrist, and fingers. It was not possible for both observers to be present for all of the tests, hence the notations on some children were made by one observer working alone. The records were made as complete as possible. For each of directions 1 (↓), 2 (→), 3 (↑), and 4 (←), 183 records on sixty-one children were obtained. At three years of age there were six children, at four years, sixteen children, at five years, twenty-six children, at six years, eight children, and at seven years, five children. For directions 5 (↙), 6 (↘), 7 (↗), and 8 (↖), seventy-two records on twenty-four of these children were obtained.

Fuller accounts of the movements made and the muscles employed might have been gained had it been possible to have motion pictures of the children as they did the test. This was not feasible at the time, however, for such a large group of children. The present analysis brings out some rather significant gross differences in the children's methods of approach. Unfortunately it could not include differences in the rhythm of movements and in the speed of the separate adjustments, which are important factors in the unity of a movement. The time for total performance was kept as usual.

The sequence of the adjustments observed is indicated in general in the discussion by describing first for each direction the

9. The writer was assisted in this work by Idell Pyle, research assistant in anthropometry in the Iowa Child Welfare Research Station.

basic movements that were carried on through the entire performance and describing next the additional adjustments that occurred as the performance progressed. At all ages, at the beginning of each of these tests the pencil was grasped by fingers 1 (thumb), 2, and 3, with 4 and 5 in free flexion, and the forearm was in a semipronated position.

For direction 1 (↓) the position taken was that of flexion of the fingers, elbow, and shoulder. The basic and predominating active movement at all ages for direction 1 was elbow flexion combined with shoulder extension, except at age seven, when wrist flexion was the primary movement, supplemented by finger flexion, and alternating with elbow flexion and shoulder extension when the wrist had reached its maximum flexion. Wrist flexion was not used at any other age. Active finger flexion was noted in some children at all ages, but more in the older children than the younger. Body torsion was notable in the three-year-old children and trunk flexion and extension were present in half of the four-year-old children, but were gradually eliminated in the older groups. Pronation was evident as early as three years, but was not largely used except at age four, when it was observed in about one-third of the children.

For direction 2 (→) the position at the beginning of the movement was elbow and finger flexion, and the basic active movements at all ages were elbow flexion and shoulder extension. Wrist flexion was not used for this direction except in the case of two seven-year-old children, since it was particularly difficult and practically impossible without elevation of the wrist from the paper. Body movements were again noted at the younger ages, although less frequently than for direction 1. Pronation occurred to some extent at all ages except age seven, and shoulder abduction at all ages except age three, when pronation and body torsion were substituted. Ulnar adduction occurred in about one fourth of the four- and five-year-old children.

For direction 3 (↑) the position was elbow flexion, shoulder flexion, and shoulder abduction. The basic active movement was elbow extension, combined with shoulder flexion at ages three, four, and five, and with wrist flexion in addition at age seven. At age six the supplementary movements were varied, pronation, shoulder adduction, shoulder abduction, wrist flexion, and body torsion occurring with some of the children and in different combinations. Ulnar ad-

duction, finger flexion, and body flexion were noted in one third of the five-year-old children.

For direction 4 (←) the position was that of elbow flexion and shoulder extension. The basic active movement was elbow extension with shoulder flexion and pronation. Body torsion and trunk extension were quite prominent in the four-year group, and trunk flexion was noted in several instances in the five and six-year groups. Some wrist flexion was present in the seven-year-old children. Ulnar adduction occurred in one fourth of the four and five-year-old children.

For directions 5, 6, 7, and 8 the number of cases was too small for age analysis of the movements. Directions 5 and 6 were largely accomplished by elbow flexion, combined with wrist flexion, and supplemented sometimes by shoulder extension and sometimes by shoulder abduction. Shoulder extension occurred in a larger number of cases in direction 6 than in direction 5, and wrist flexion was more prominent in direction 5 than in direction 6. Finger flexion was prevalent for both directions. For directions 7 and 8 elbow extension, shoulder abduction, and shoulder flexion were the basic movements. Ulnar adduction was used by practically all of the six-year-old children, and by some of the five-year-old children, although pronation was more common at five years. Radial adduction was used by some children at seven years and wrist extension by some.

In summing up the results for all of the directions, it is found that body movements—body torsion, trunk flexion, and trunk extension—were common among the younger children, that these body movements were gradually eliminated as age increased, and that localization of control in the wrist was prevalent among the older children.

What are the muscular adjustments, apart from those mentioned in relation to age, that a child makes who earns a high score on the test and how do they differ from those of the child who earns a low score? To throw light on this question some individual records were compared. Two pairs of children of the same age were selected on the basis of widely differing scores, one child of each pair making consistently high scores and the other child making consistently lower scores. The active movements of each child in the pairs are presented here:

Pair I

F28	M 27
Age: 3 years, 10 months	Age: 3 years, 10 months

Direction 1 (↓)

Score 94	Score 73
Finger flexion	Finger flexion
Elbow flexion	Elbow flexion
Shoulder abduction	Shoulder abduction
	Ulnar adduction
	Pronation
	Shoulder extension

Direction 2 (→)

Score 92	Score 64
Elbow flexion	Elbow flexion
Shoulder abduction	to
Finger flexion	Elbow extension
Wrist extension	Shoulder adduction
Ulnar adduction	Pronation
to	Body torsion
Radial adduction	

Direction 3 (↑)

Score 76	Score 49
Finger flexion	Finger flexion
Elbow extension	Elbow extension
Shoulder flexion	Shoulder flexion
Shoulder abduction	Ulnar adduction
Radial adduction	

Direction 4 (←)

Score 81	Score 60
Finger flexion	Ulnar adduction
Radial adduction	Shoulder flexion
to	
Ulnar adduction	
Elbow extension	
Shoulder abduction	

Pair II

F 31	M29
Age: 4 years, 1 month	Age: 4 years, 0 month

Direction 1 (↓)

Score 94	Score 78
Elbow flexion	Elbow flexion
Body flexion	Body flexion
Finger extension	Pronation
Shoulder extension	Shoulder flexion

Direction 2 (→)

Score 91	Score 78
Elbow flexion	Elbow flexion
Ulnar adduction	Wrist flexion
to	Pronation
Radial adduction	to
	Supination

Direction 3 (↑)

Score 95	Score 47
Elbow extension	Elbow extension
Shoulder flexion	Shoulder flexion
	Pronation

Direction 4 (←)

Score 85	Score 51
Elbow extension	Elbow extension
Shoulder flexion	Shoulder flexion
Pronation	Pronation
Wrist flexion	Body extension
Radial adduction	Body torsion

The two girls who earned the higher scores were from one and one-half to two years beyond their age level in score, while the two boys made scores at about their age level. Comparison of the movements of the two members of a pair show that there were differences between the movements made by the child earning a high score and the movements of the child earning a low score. There were also differences between the movements made by the two children earning high scores, which were practically as great as the differences between the members of a pair. In only two instances the two high scorers used an identical movement that was not used by the poor scorers. These instances were for direction 2, on which the high scorers used ulnar adduction, which was changed to radial adduction as the movement progressed, and for direction 4, on which they used radial adduction. Pronation in directions 1 and 2 was the only movement used by both low scorers that was not used by the high scorers. These results seem to point to the conclusion that the adjustments were probably matters of individual differences and that the explanation for the likenesses and differences in scores for two children of the same age must be sought elsewhere than in the types of adjustments observed.

A pair of children was also selected on the basis of scores comparable with the scores of the other two pairs, but the members of which differed in age. One child was five years, two months old and the other three years, six months old.

PAIR III

M 36 Age: 5 years, 2 months	M 25 Age: 3 years, 6 months
Direction 1 (↓)	
Score 96	Score 71
Finger flexion	Finger flexion
Pronation	Pronation
Elbow flexion	Elbow flexion
Shoulder adduction	Wrist flexion
	Radial adduction
	Shoulder extension
	Knee flexion
Direction 2 (→)	
Score 95	Score 52
Finger flexion	Finger flexion
Pronation	Pronation
Shoulder abduction	Shoulder abduction
Wrist extension	Knee flexion
Elbow flexion	
Direction 3 (↑)	
Score 97	Score 70
Finger flexion	Finger flexion
Elbow extension	Body flexion
Shoulder abduction	
Direction 4 (←)	
Score 94	Score 51
Finger flexion	Finger flexion
Wrist extension	Elbow extension
Elbow flexion	Shoulder extension
	Body torsion

In this pair the most marked differences in movement were in the presence of knee flexion, body flexion, and body torsion in the three and one-half-year-old child and in the absence of these body movements in the five-year-old child.

INDICATIONS OF PRESSURE

It was noted from observation of the movements, particularly flexion of the fingers and pronation, and by the shade of the line produced that during a trial the children used varying amounts of pressure upon the pencil. A permanent record of the amount of pressure was desired, if such could be obtained without changing the conditions of the test. Complicated apparatus for recording pressure such as that used by Freeman[29] in his writing experiments did not seem advisable with these young children.

Dental wax was first placed under the test sheets and the test given in the usual manner. Inspection of the wax afterwards showed

that there were changes in the amount of pressure during a trial. These variations showed as clearly, however, on the back side of the test papers themselves, whether the wax or beaverboard was underneath, since the beaverboard was also relatively soft. Where the pressure was extreme, the pencil point nearly broke through the paper; where it was slight, the line was not visible on the opposite side.

There were considerable individual variations in the amounts of pressure exerted. Most children used more pressure at the beginning of the trial than in any other part. This heavier pressure lasted about 1 or 2 cm., and in exceptional cases about 5 cm.; then the line became lighter and lighter until at the end of the trial the line was not visible on the back of the sheet. If a child went off the path, stopped and began a new line within the path, instead of continuing his movement and swinging back into the path, as happened in a few cases, the new line which was begun showed the same greater pressure at the beginning.

Another method of determining relative pressure on the pencil was by the depth of the imprints in plasticene that had been wrapped around the pencil about 3 mm. thick. The plasticene was a somewhat distracting factor; the children asked, "Why do you put clay around it?" Twenty-four records on six children and one record each on three adults were obtained. The pressure used by one adult who had had considerable training in penmanship was so light that the positions of the fingers could not be determined later. Individual differences existed among the children, but the pressure was sufficient in every case to make a decided imprint on the plasticene, the pressure usually being greatest with the forefinger and next with the thumb. Of the other two adults, one used less pressure than the children, and the other used greater pressure than any of the children, the greatest pressure in her case coming from finger 3, in contast with the other two adults, who, like the children, exerted most pressure with fingers 1 and 2.

TIME FACTORS IN MOVEMENTS

In the main experiment the total time of performance was recorded by means of a stop watch. A special experiment was made in order to determine the length of time the child spent in the various parts of the movement. Light pencil dots were placed on the test sheets 2 cm. apart and about 2 cm. outside the guidelines. The child took the test in the usual manner, while the experimenter sat at the

end of the table with a stylus and tapping apparatus on her lap under the table and out of the range of vision of the child. As the child passed each dot the experimenter tapped and the taps were recorded on a kymograph drum in the adjoining room. This method of course involved the reaction time of the experimenter, but all records were made by the same experimenter. A time line was taken simultaneously in fifths of a second by a standard chronometer. Most of the children did not notice that the experimenter held the apparatus, and the test was in every other way comparable to the standard method. Fifty-seven time records were taken.

An examination of the time records shows a tendency to a very slow rate for the first 2 cm., or starting of the movement with a gradual increase in speed through the central portion of the path, a gradual decrease for the latter portion, and the slowest rate for the last centimeter, with stopping of the movement.

Special conditions, however, operated to change the speed. If the child got outside or too near the guidelines he slowed up until he felt that he was safely back again. Occasionally a child slowed up or stopped entirely to make some remark. Since these changes in the rate of movement were for the most part brought about by the attempt of the children to keep within the confines of the guidelines, general conclusions can not be made on the rate of speed they would take in drawing lines under different conditions. In a majority of the cases the first trial took considerably longer than either of the other two trials. This is in agreement with the findings on total time taken by the stop watch method during the course of the main experiment. Figure 7 is a sample record which illustrates some of these tendencies.

FREELINE MOVEMENTS

In order to test whether the sharp turns and curves in the lines made by the children were due to lack of muscular control or to psychological factors, a variation of the test was devised. After a rest or play period following a test given in the usual way, the child was brought back and given sheets of paper on which were two dots 25 cm. apart. The instructions were: "See this dot [pointing] and this dot [pointing]. I want you to make a mark from this dot to this dot." Thirty records on dot tests were secured.

Figures 8 and 9 show three trials each in the same directions with the guidelines and with the dots for a girl (F30) and a boy (M12).

Fig. 8. F30, at four years, five months, took twenty-two seconds, thirteen seconds, and nineteen seconds for the three trials on direction 7 (↗) with the guidelines, but only seven seconds each for the three trials on the same direction without the guidelines.

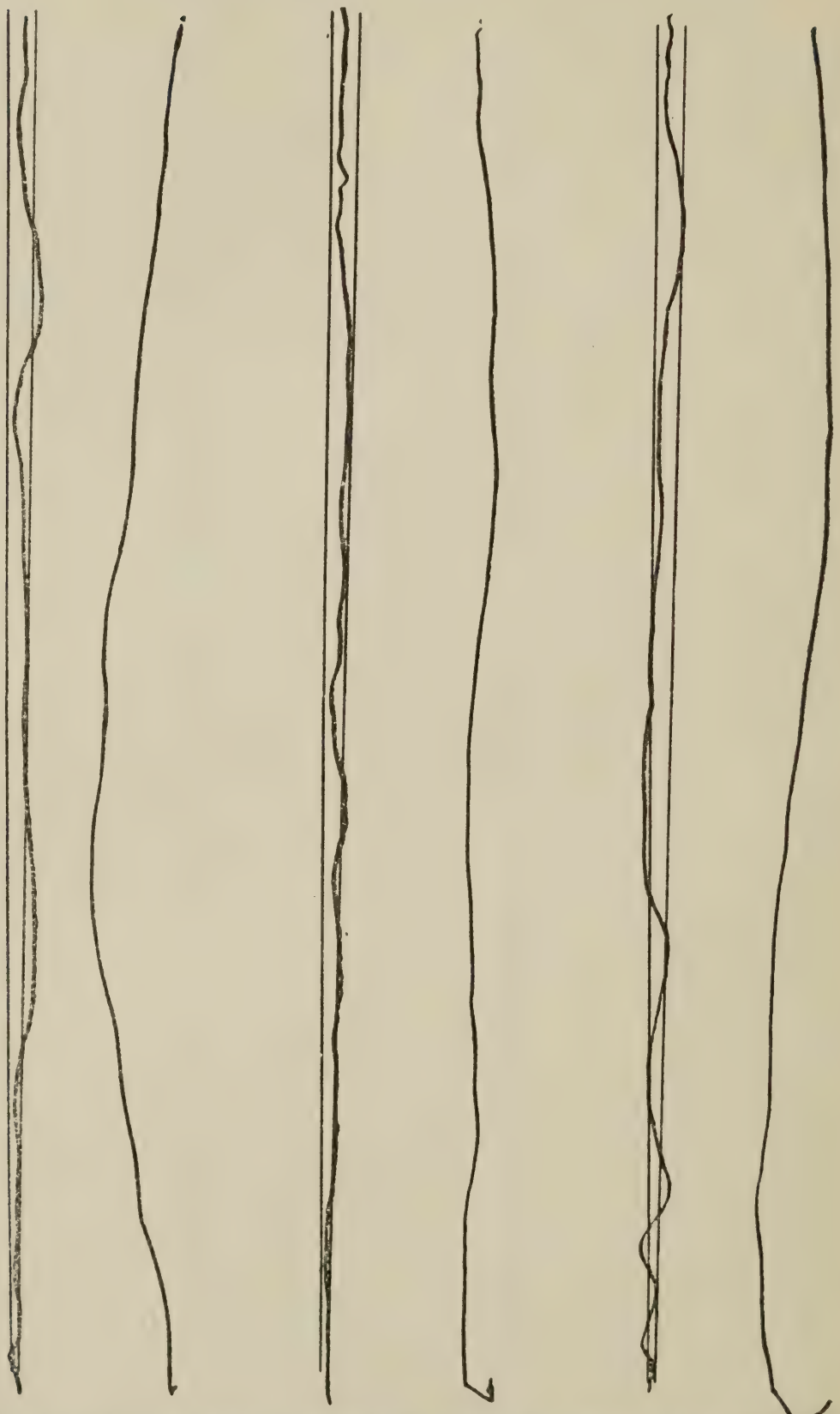

Fig. 9. Abrupt changes in freeline movement were made by M12, aged three years, six months, when he missed the dots on the second and third trials on direction 1 (↓).

The most outstanding feature of the dot records is their freedom from curves and angles when compared with the guideline tests. When the child realized that he was moving in a direction that would bring him away from the dot, he shifted the direction of movement gradually, as is illustrated in the second trial with the girl and the first trial with the boy. Sometimes when the realization that the dot would be missed came late, as in the case of the second and third trials with the boy, sharp turns were made.

Another characteristic of the dot test is that the trials consumed very much less time than the guideline trials. The three trials with the guidelines for the girl took 22 seconds, 13 seconds, and 19 seconds, respectively and with the dot test 7 seconds each. For the boy, the differences were even greater, the time being 22 seconds, 21 seconds, and 16 seconds on the three trials of the guideline tests, and 4 seconds, 4 seconds, and 5 seconds on the dot tests. Similar differences in time and in type of line were noted for all of the children tested.

It would seem, then, that the curves and angles in the lines on the tracing path were products of conscious attempts to keep within the path and of inhibitions aroused by the guidelines, since it has been demonstrated that the children were capable of making straighter lines when the guidelines were absent. There is probably no physiological reason why such fluctuations should have appeared, unless possibly the slower rate that was adopted voluntarily may have tended to cause unsteadiness.

Test records with the dots differed from those with the guidelines also in the amount of pressure; with the dot test there was not greater pressure at the beginning of the trials, as with the guidelines, and the pressure was almost uniform for the entire length of the trial. Children who exerted decided pressure at the start with the guidelines failed to exert this pressure when the dots were substituted. Apparently the greater pressure at the beginning of a trial was not a necessary part of getting a movement started, but came about from an attempt to make an accurate adjustment within the guidelines.

Differences in the focusing of the eyes for the two tests were also observed. The examiner sat in a low chair beside the child and could easily watch the movements of the child's eyes without distracting the child. Notations were made of the eye movements of the children in thirty-three tests. When the child made the freeline move-

ment, he usually looked at the first dot until he had progressed about 5 cm., then he shifted his gaze to the goal dot and kept it focused there until he had finished. Some exceptional children made a supplementary shift or two back to the pencil and then to the goal dot again. When the guideline test was given, the eye shifts were more frequent for the same children and took in smaller units. There was not the large shift to the end of the path, but the progress was gradual in fairly definite units. Sometimes there were movements of the head in addition to movements of the eye. The highest number of definite movements of the eye observed for any trial was thirteen, made by a child whose average number of shifts for the guideline test was 8.5, plus turning of the head, and whose average number of shifts for the dot test was four, this being above the average of all children for the dot test. What evidence is at hand seems to indicate that the eye movements were not important of themselves, but were indicative of mental processes. The number of cases studied was small, but the same conditions were observed in all instances. More data are needed on this phase of the problem.

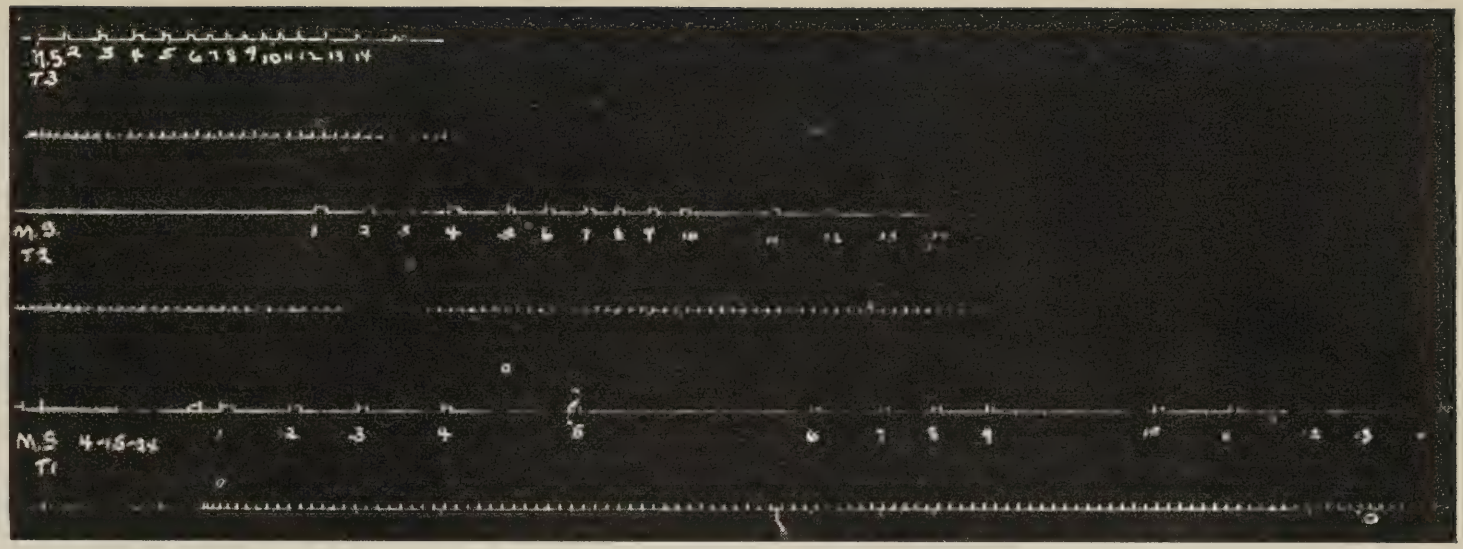

Fig. 7. Three trials in one direction by F44. The time is indicated by short lines at regular intervals of 1/5 second. The child's record, in centimeters, is indicated by numbers, at intervals of 2 cm. each, except the last interval, which is 1 cm.

The first trial took 23 seconds, the second, 10.8, and the third, 6.4. The longer time on the first trial (T1) from dots 3 to 6 is explained by the fact that the child went off the path between 2 and 3 and immediately slowed down. Between dots 5 and 6 she broke the lead of her pencil, and between dots 9 and 10 she went off the path, lifted her pencil, and began back up the path.

In the second trial, the child touched the guideline between dots 2 and 3 and 3 and 4, but managed to keep in the path, and then swept along until she went off the path between dots 9 and 10, after which she slowed down.

In the third trial, the child kept in the path until dot 8, gradually increasing her speed. In this trial she did not slow down immediately after she went off the path, but she decreased her speed noticeably in order to stop the movement. The failure to slow down immediately may have been due to inability to check at once the rapid movement she was making, or to a desire from some ulterior motive to finish the trial as quickly as possible.

CHAPTER VI

MOTOR CO-ORDINATION, PHYSICAL GROWTH, AND INTELLIGENCE

It seemed worth while to inquire whether any relation existed between the types of motor coördination involved in this investigation and physical growth, intelligence, and various other types of motor coördination.

MOTOR CO-ORDINATION AND PHYSICAL GROWTH

Physical measurements taken each month were available on all of the children. These measurements were taken by research assistants in the Iowa Child Welfare Research Station according to the technic described by Baldwin.[10] Height, length of forearm, length of upper arm, and area of wrist bones were selected for the correlations, which are given in Table 31.

The raw correlations for each sex from three to six years of age between the physical measurements and point of first contact on the tracing board were high. When age was held constant there was apparently a positive relation with height for boys and girls, and with length of forearm and of upper arm for the girls but not for the boys. In view of the peculiar differences between sexes, however, the correlations probably should not be relied upon greatly.

The raw correlations between the average scores on all directions on the tracing path and the physical measurements were also high, but when age was held constant the correlations lost their significance.

From these correlations it can not be stated what the relationship is within an age group between physical size and the motor coordinations involved in these tests.

MOTOR CO-ORDINATION AND INTELLIGENCE

Mental age on the Stanford-Binet test was calculated to the time at which the tracing board and tracing path tests were given, on the basis of the constancy of the intelligence quotient. When the group

10. Baldwin, B. T. Physical Growth from Birth to Maturity. *Univ. of Iowa Stud. in Child Welf.*, 1921, 1, No. 1. Pp. 411.

TABLE 31
Correlations between Physical Measurements and Average Scores of the Eight Directions Combined on Point of First Contact on the Tracing Board and on the Tracing Path

Physical measurement	Boys		Girls		Age constant			
					Boys		Girls	
	r	P.E.	r	P.E.	r	P.E.	r	P.E.
Tracing board								
Height	.85	± .04	.58	± .08	.36	± .12	.30	± .12
Length of forearm	.71	± .07	.63	± .08	−.07	± .13	.41	± .10
Length of upper arm	.71	± .07	.62	± .08	−.15	± .13	.39	± .11
Tracing path								
Height	.78	± .03	.72	± .04	.17	± .08	.02	± —
Length of forearm	.74	± .04	.67	± .04	.15	± .08	−.01	± —
Length of upper arm	.74	± .04	.67	± .04	.15	± .08	.02	± —
Area of wrist bones	.56	± .07	.65	± .05	.01	± —	−.12	± .09

included children from three to six years of age, the correlations between the point of first contact on the tracing board for all eight directions combined and mental age were .71±.07 for the boys and .66±.07 for the girls. When chronological age was held constant, the correlations became —.46±.11 for the boys and .46±.10 for the girls. The differences between the sexes are again difficult to interpret.

For all children, the correlations between mental age and the tracing path scores for all eight directions combined were .73±.04 for the boys and .76±.03 for the girls. When age was held constant, the correlations were .09±.08 for the boys and .22±.07 for the girls.

The correlations of the two tests with mental age were about the same size as the correlations with physical measurements. There was apparently no greater relationship between the coördinations involved in these tests and mental age than there was between these coördinations and physical development.

MOTOR CO-ORDINATION ACCORDING TO VARIOUS MEASURES

It was possible to determine whether the coördinations involved in the tracing board and tracing path tests were similar to those involved in other measures of motor ability, since five other tests that involve motor coördination to a large extent had been given to this group of children by the research assistants. These five tests were the Porteus maze, a perforation test, card sorting, three hole, and walking board. The technic of giving these tests and the method of

scoring are given in Baldwin and Stecher's[5] *Psychology of the Preschool Child.*

For the point of first contact on the tracing board the correlations with the perforation test were the highest of the five when chronological age and mental age were held constant, whereas for the tracing path they were the lowest. The correlation between the card sorting and tracing board tests dropped to .08 when mental age was held constant, whereas with the tracing path there was a cor-

TABLE 32
Correlations between Motor Tests and Average Scores of the Eight Directions Combined on Point of First Contact on the Tracing Board and on the Tracing Path

Motor test		Age constant	
		Chronological	Mental
	r P.E.	r P.E.	r P.E.
Tracing board			
Porteus maze	.62 ± .06	.31 ± .09	.28 ± .10
Perforation	.69 ± .05	.50 ± .07	.45 ± .08
Card sorting	.65 ± .07	.32 ± .10	.08 ± .10
Three hole	.66 ± .06	.32 ± .09	.20 ± .09
Walking board	.42 ± .09	.19 ± .10	.12 ± .10
Tracing path			
Porteus maze	.76 ± .05	.54 ± .08	.45 ± .09
Perforation	.56 ± .07	.11 ± .10	.09 ± .15
Card sorting	.86 ± .03	.50 ± .09	.49 ± .09
Three hole	.76 ± .03	.22 ± .07	.32 ± .07
Walking board	.61 ± .07	.20 ± .11	.26 ± .10

relation of .49. There was apparently no relationship between the scores on the walking board and tracing board tests when chronological age and mental age were held constant, and there were but low partial correlations between the scores on the Porteus maze and the tracing board tests and between the three hole and tracing board tests.

The raw correlations between the tracing path scores and the five tests were high. When chronological age and mental age were held constant the correlations with the Porteus maze and with the card sorting test scores were still significant and substantial, indicating that the tracing path test had something in common with these two tests apart from the influence of chronological age and mental age. There was practically no correlation between the scores of the per-

foration test and the tracing path test when chronological age and mental age were held constant; there was a tendency toward a correlation between the scores of the walking board and tracing path tests, and a low but probably significant correlation between the scores of the three hole test and tracing path tests when chronological age and mental age were held constant.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Observation convinces one that there are individual differences in the ability of young children to meet the demands that are constantly being made upon them for the coördination of movements. The investigation reported herein deals with some phases of these differences in motor coördination of young children, with particular emphasis on the analysis of the influence of direction of movement on control of hand and arm movements and on the analysis of the psychological and muscular factors involved in this control.

A child's ability to make movements in eight primary directions was tested in a preliminary experiment with a modification of the Stoelting tracing board as the apparatus, and later with a tracing path that was devised to remedy some special difficulties with the tracing board. The directions of the movements were:

down
left to right
up
right to left
right to left down
left to right down
left to right up
right to left up

In the tracing path test the child was asked to draw a line on a sheet of paper between two printed lines 25 cm. long and 5 mm. apart at one end and 1 mm. apart at the other end.

The subjects included 136 children from three to six years of age in the Preschool Laboratory and Junior Primary Group of the Iowa Child Welfare Research Station and in the first grade of the Elementary School of the State University of Iowa; many of the children acted as subjects for repeated tests and special experiments.

The most significant results of the investigation are summarized herewith:

1. The tracing path test was found to be more satisfactory for purposes of detailed analysis of movement and to give more reliable scores than the tracing board test.

2. The reliability of the tracing path test ranged from .88 at three years to .95 at five years. When the age range was from three to six years, the reliability was .98±.002 for the tracing path test and .90±.01 for the tracing board test.

3. Scoring the results of the tracing board test by the method of percentage within the path brought the results into closer agreement with the results on the tracing path test than scoring by the usual point of first contact on the tracing board.

4. No sex differences were found in scores on either test.

5. The tracing path test was applicable to children two years, nine months of age and older.

6. The older child went a longer distance before making contact on the tracing board than the younger child. The older child kept within the path for a longer distance on the tracing path. The scores at six years nearly doubled those at three years. The correlation between age and the combined score on eight directions on the tracing path was .81±.03 for the boys and .82±.03 for the girls from three to six years of age.

7. Different types of movements were made at the various ages. Body movements (torsion, trunk flexion, trunk extension, and knee flexion) were more common among the younger children, while control was localized in the hand and wrist among the older children. There were wide individual differences in types of movements.

8. A child who made a high score on one direction on the tracing path tended to make a high score on another direction. The correlations between scores based on the average of three trials were significant and high, ranging from .80±.03 to .89±.01 when the group included children from three to six years, and from .32±.12 to .90±.03 when year groups were used.

9. Movements with the left hand were more difficult than movements with the right hand. The difference between the two hands became greater as age increased. Children who made more accurate movements with the right hand than others of the group also made more accurate movements with the left hand.

10. Movements in directions left to right and right to left were particularly difficult for the children to make with the right hand. Movements from right to left were especially difficult with the left hand also. Movement from left to right was easier in comparison with the other movements for the left hand than for the right hand,

and many of the children's actual scores with the left hand on this direction exceeded their scores with the right hand.

11. There was less deviation from a true straight line for the angle direction right to left up than for any other direction with the right hand. This was probably the easiest direction. The greatest deviations were on directions down, left to right, and right to left.

12. Quicker movements and straighter lines were made when the inhibiting effect of the printed guidelines was removed than when the guidelines were present.

13. There was a speeding up from direction to direction within a day's test, apparently due mainly to motor habituation.

14. The first trial was more accurate than the second and third trials and took a longer time.

15. Speed changes within a trial were conditioned by special factors of attention. Initiating and inhibiting a movement required a slower rate than continuing a movement.

16. Children who took the test twice made higher scores the second time than other children at the same ages, although their first scores were not higher than the scores of other children at the same ages.

17. There was no apparent transfer of training from one direction to another.

18. Children who made high scores on the tracing path test also made high scores on the Porteus maze and card sorting tests, even when the influence of mental age and of chronological age on the scores was eliminated. There was a tendency for them also to make high scores on the three hole and walking board tests, but not on the perforation test.

19. There was apparently no greater relationship between the coördinations involved in the tracing board and tracing path tests and general intelligence than between the coördinations and physical development.

These results suggest the need for continuation of the present investigation with special reference to some specific phases of development of motor coördination. Further study is needed to determine what would be the effect of altering the sequence of directions tested, and to determine which directions should be included and which can be discarded in measuring as accurately as possible a child's ability to coördinate his movements. Such questions as the relation of

motor control to physical development and to general nervous stability can be answered best by the accumulation of larger numbers of records at specific ages. The question of what effect training has upon motor control in young children can best be answered by repeated measurements on the same children. The present investigation has dealt with movement over a specified distance. It remains for further investigation to determine whether similar results will be obtained when shorter or longer distances are involved.

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